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Muskegon County Board, MI

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16. ABSTRACT

The Muskegon County Wastewater Management System is a lagoon-impoundment, spray irrigation treatment facility which serves 13 municipalities and five major industries. The system consists of a 4,455 hectare site (11,000 acre) site which contains three aeration ponds, two storage lagoons totaling 688 hectare (1700 acres) and 2,200 hectares (5,500 acres) of land irrigated by center-pivot irrigation rigs. The system is provided with a network of subsurface drains, open interception ditches and shallow wells to make possible the monitoring and control of the quality of water throughout the treatment process. With an average daily flow of 106 thousand cubic meters (28 million gallons) in 1975, the system provided discharge of water of a quality consistently above NPDES specifications. Studies on various aspects of treatment performance, agricultural productivity, and the interrelationships of soil-crop-nutrient chemistry are here reported, including discussions of the socio-economic impact of the project, its early history, a description of its operation and maintenance, and an overview of project economics.

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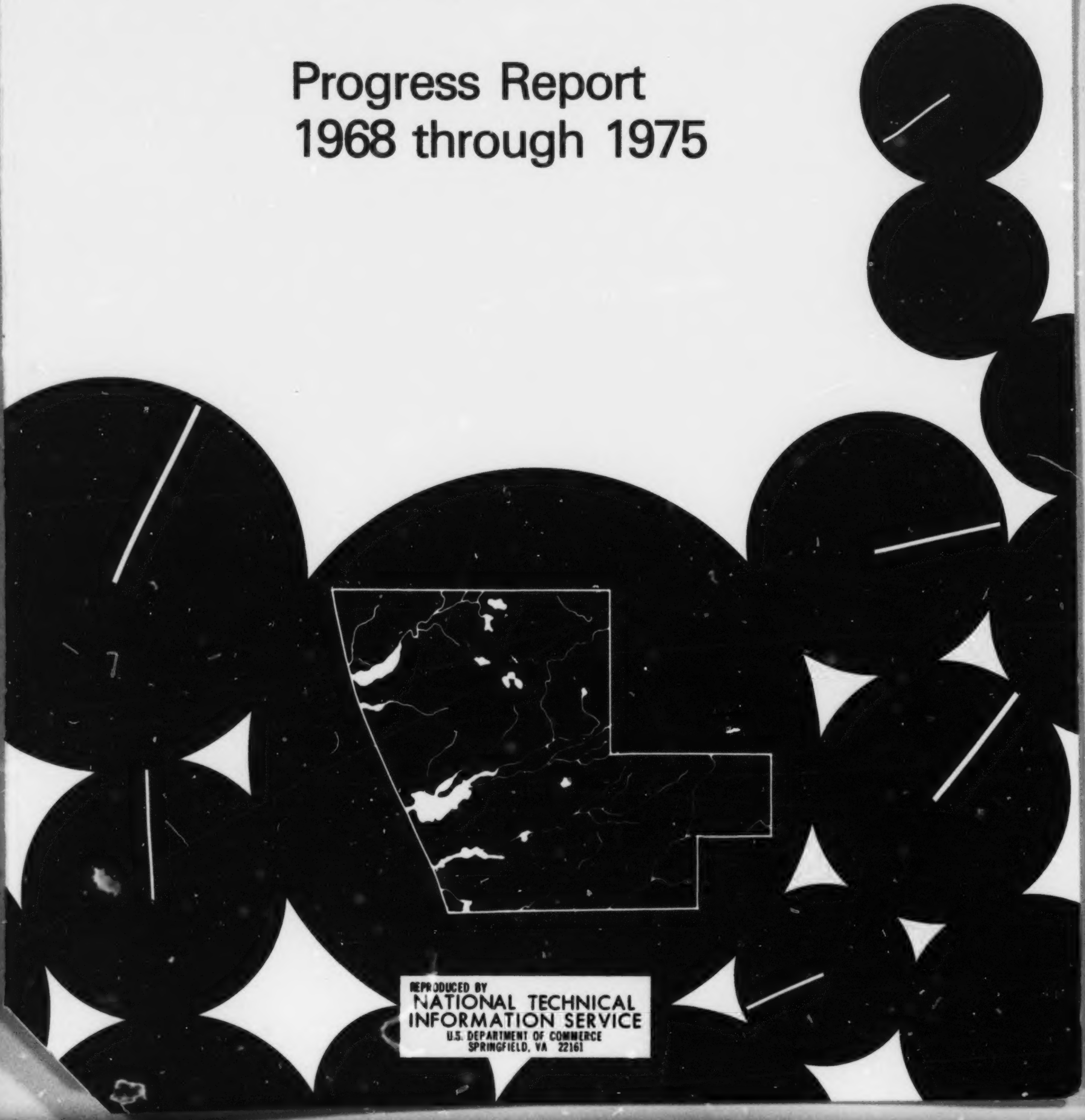

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MUSKEGON COUNTY
WASTEWATER MANAGEMENT SYSTEM

Progress Report
1968 through 1975

by

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Muskegon, Michigan 49442

Project 802457

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This report has been reviewed by the Robert S. Kerr Environmental Research Laboratory and Region V, Chicago, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constititute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques, and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate, and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewater with soil and other natural systems; (c) develop and demonstrate pollution control technologies to prevent, control, or abate pollution from the petroleum refining and petrochemical industries; and develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

The Great Lakes National Program Office (GLNPO) of the U.S. EPA was established in Region V, Chicago, to provide specific focus on the water quality concerns of the Great Lakes. Land disposal of wastewater in the Great Lakes area is one alternative for treatment that can provide tertiary quality effluent when properly managed. Local decision makers must implement management practices that will best solve their pollution problems.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C. Galegar
Director
Robert S. Kerr Environmental Research Laboratory

Madonna F. Mc Grath
Director
Great Lakes National Program Office

ABSTRACT

The Muskegon County Wastewater Management System is a lagoon-impoundment, spray irrigation treatment facility which serves 13 municipalities and five major industries. The system consists of a 4,455 hectare site (11,000 acre) site which contains three aeration ponds, two storage lagoons of 344 hectares (850 acres) each and a total storage capacity of 19.3 million cubic meters (5.1 billion gallons), and 2,200 hectares (5,500 acres) of land irrigated by center-pivot irrigation rigs. The system is provided with a network of subsurface drains, open interception ditches and shallow wells to make possible the monitoring and control of the quality of water throughout the treatment process.

With an average daily flow of 106 thousand cubic meters (28 million gallons) in 1975, the system provided discharge water of a quality consistently above NPDES specifications. Studies on water quality and soil-crop-nutrient balance revealed that by balancing the nutrients in wastewater with crop needs, more effective overall nutrient removal was achieved, simultaneously enhancing crop production and wastewater renovation. Revenues from crop sales are returned to the system to ameliorate treatment costs which in 1975 amounted to less than $28 per thousand cubic meters ($106 per million gallons).

Studies on various aspects of treatment performance, agricultural productivity, and the interrelationships of soil-crop-nutrient chemistry are here reported, including discussions of the socio-economic impact of the project, its early history, a description of its operation and maintenance, and an overview of project economics.

This report was submitted in partial fulfillment of Project Number 802457 and Grant Number 11010GFS by the Muskegon County Wastewater Management System, Muskegon, Michigan, under the sponsorship of the Environmental Protection Agency.

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SECTION 1

INTRODUCTION

PLANNING AND CONCEPTION

Industrial communities frequently experience economics which vacillate between boom and bust. Muskegon County has many industrial communities which, during the decade of the 1960's, were suffering economic doldrums. Unemployment was high, and industries were leaving the area. Tourism was down. Water pollution was severe.

The natural resources of Muskegon County are ample: the western boundary is the shoreline of Lake Michigan, and there are several inland lakes and streams of great potential for development of recreational and tourist-related industries. But industrial effluent was being discharged directly into streams, and most municipal wastewater was receiving only minimum primary treatment before being dumped into the county's waterways. It was clear that economics and aesthetics were intertwined: dirty water was choking the regional economy.

Among the many plans and suggestions before the Muskegon County Planning Commission at this time was a proposal for a county-wide wastewater treatment facility. The feasibility of the plan was enhanced by the fact that most of the industries and population densities are located in a centralized area between Mona and Muskegon Lakes. See Figure 1. It was argued that such a treatment facility would renovate the county's waters so that one could expect the lakes and streams to regain their attractiveness, and this attractiveness would be reflected in the communities bordering them. The appeal would be diverse: to tourists and therefore to local businesses; to industrial investment and therefore to the gainfully employed; even to wildlife and to all who appreciate wildlife. The scope and purpose of this scheme for clean water were far-reaching: to blend advantageous socio-economic considerations with an overall improvement in environmental quality.

The task of putting together and planning a county-wide wastewater treatment plant with the involvement of five major industries and 13 municipalities was formidable.

During the early period when the proposal was under consideration, the Muskegon County governmental structure was comprised of a board of supervisors of 45 members broken up into some 32 committees. Members of the board were either elected as township supervisors or city commissioners, or were appointed by the local municipality. Each member's primary allegiance was to his specific constituency, and to achieve concord on county-wide programs was difficult in the extreme. It seemed unavoidable that if progress were to be made, the form of the county government must first be changed.

In 1968, the United States Supreme Court decided the Avery case, and the effect of the decision

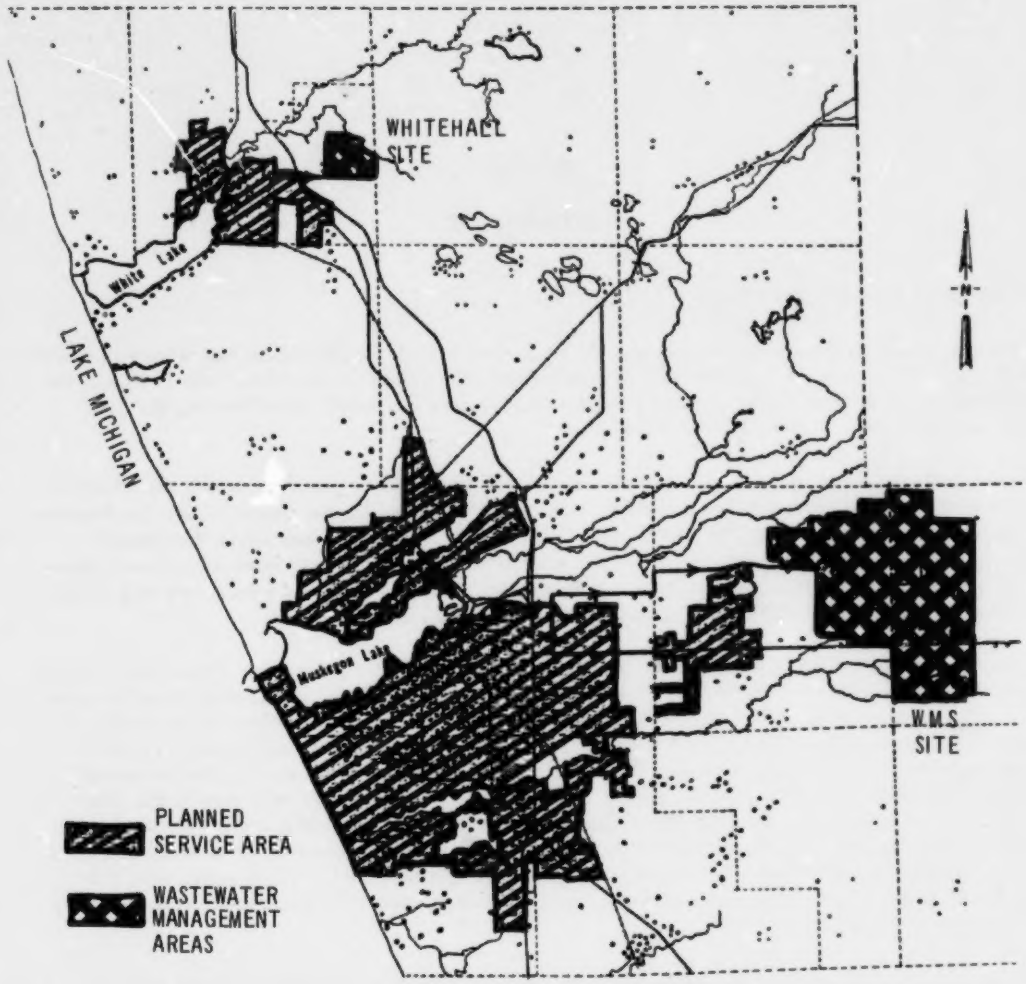


Figure 1. Site location

was to extend the one-man, one-vote concept to local government.[1] In that the county commissioners were elected from geographical districts of nearly equal population, the Avery decision was to assure that each commissioner would represent an equal number of constituents.

In 1968, the first election was held for the re-apportioned County Board of Commissioners – the name was changed from "supervisors" to "commissioners." The new 15 county commissioners elected a chairman and appointed a corporate counsel and a comptroller and a director of the Department of Public Works. It was within this structure of county government that the wastewater management system was to be eventually realized, but not without great difficulty. The membership of the new board of commissioners had little, if any, prior experience in county government, and as they assumed their new posts they were facing an existing deficit of over $250,000.

The county wanted to establish a regional system of wastewater treatment. But at the same time, the City of Muskegon had on the drawing board plans to expand their plant into secondary-tertiary treatment system, and the City of Muskegon Heights was already in the process of expanding its system of secondary treatment and phosphate removal. These cities and others in the area were in various stages of applying for state and federal funding for their improvement plans. If the county-wide concept were to be accepted, the provincial and hometown-first priorities would have to be altered.

In 1968, the Muskegon County Planning Commission engaged the services of a planning consultation firm in Chicago, Bauer Engineering, Inc., to perform a feasibility study. The Bauer firm gave to the board of commissioners a presentation on the benefits and cost-effectiveness of land treatment of wastewater. Board members learned that a pilot project employing these principles was being done at Pennsylvania State University. After visiting Penn State and making further detailed inquiries throughout the year of 1969, the board of commissioners began to seriously consider land treatment as a plausible alternative for their region. In February, 1969, the commission adopted a policy resolution to the effect that the county would take measures to clean up the environment and, specifically, while providing higher quality surface waters, also encourage industrial expansion. But outside of the board itself, there was little enthusiasm for this bold experiment; skepticism ran high in all segments of the communities, and local governments continued to compete with the county in the solicitation of priorities for state and federal financial aid.

The impetus that was needed came in the form of the Lake Michigan Tributaries Conference of four states which resulted in an agreement among the four states that by 1972 discharge of unclean water into Lake Michigan would cease. Two important features were: the 1972 deadline which forced action and discouraged delay, and the fact that sources of federal monies gave notification that funding would be done only for projects with regional wastewater objectives. The Muskegon County Board of Commissioners, being the only organization with a regional plan, was then in a good position to prevail.

Several municipalities were in trouble because of the conference agreement. The City of Muskegon received notification from the S. D. Warren Paper Mill, the city's largest wastewater contributor at 60.6 thousand cubic meters per day (TCMD) or 16 million gallons per day (MGD), that the company had decided not to join the city's proposed system. The reasons were essentially cost related. Later, S. D. Warren representatives were to be influential in persuading city officials to support the county approach.

During Thanksgiving week of 1969, Dr. William Bauer and members of his engineering consulting firm attended a meeting of the Muskegon County Board of Commissioners. The board voted 14-0 (with one member absent) to proceed with the plan of land treatment with wastewater as thus far outlined. Dr. Bauer was instructed to begin feasibility studies and detailed plans for the treatment system.

The board was next confronted with the task of selling their wastewater treatment idea. Because of the novelty of the concept, it was necessary to overcome skepticism and to "educate" at all levels: state, federal, and local. The State of Michigan Health Department insisted that it was an untested idea and questioned the soundness of the treatment procedure. The Health Department's reticence and lack of support was reflected in the relatively low funding priority that had been given the county by the State of Michigan.

The county board believed that there was a possibility of the project getting mired in political squabbling. The board's members were primarily Democratic, so it was decided to obtain the philosophical support of the Board of Commissioners of Ottawa County, an adjacent county whose board was exclusively Republican. The Ottawa Board was intrigued with the overall wastewater plan and agreed to lend whatever help they could. They did help in lending a flavor of nonpartisanship to the support of the Muskegon plan; it was possible to convince both Republicans and Democrats of the wisdom of land treatment.

William Milliken, Governor of Michigan, had several advisors who were less than convinced about the Muskegon project. The Muskegon County Board of Commissioners went to Lansing for several meetings with the Governor and his assistants, and with the later support of a few state congressmen and senators, gradual acceptance of the idea was obtained from Lansing.

Promotion of the project in Washington, D.C. was done by Congressman VanderJagt of the 9th Congressional District. Mr. VanderJagt was convinced of the merits of the proposal, and he publicized it well in Washington, soon obtaining the support of the Federal Water Pollution Control Administration. There were reports, unofficially, that President Nixon was aware of the land treatment scheme and that he, too, supported it.

At the local level, there had been almost no public reaction because throughout the planning stages, the program had maintained a low news profile. With increased publicity, however, citizen interest increased, and local governmental units began asking questions regarding health standards, finances, and impact on resources. The early meeting held by the county board in the Townships of Moorland and Egelston were poorly attended, but after the adoption of the plan and the decision to locate the site within these townships, there was vigorous opposition by the residents. One local environmental group also questioned the soundness of the scheme and threatened to interfere with and delay the project, so the county instituted a declaratory judgment suit to eliminate delays and interference.[2] The court ruling was in favor of the wastewater management system project. The court's ruling, coupled with many meetings with local citizens, led to an increased understanding of the operation of the project and resulted in diminished opposition at the grass roots level. Similarly, local industries became convertees to the concept of the county system and exerted meaningful pressure within their respective political units, and these pressures assisted in breaking down inter-municipal, intra-county conflicts.

S.D. Warren Company was instrumental in aligning the City of Muskegon with the county system. The City of North Muskegon was the first to contract to join the county system. Muskegon Heights finally agreed to join after negotiating arrangements for a system of credits to be allowed the city for their secondary treatment system. The trend provided sufficient incentive for the surrounding, smaller municipalities, and once they had committed themselves, the county met qualifying requirements for state and federal funding.

Many of the smaller cities and townships in the county had no collection systems. After extensive negotiations with all units, the staff of the county board, in collaboration with Dr. Bauer, drafted an access rights agreement by which a municipality might join the county system at a cost based upon the number of acres serviced. That debt service to pay off a $16 million bond issue is $25 per acre per year, and the governmental units are guaranteed that such capital costs will not fluctuate, independent of the time they join the system or the number of acres they originally commit to be serviced. The access rights agreement was well received. The debt service is divided as follows: 60 percent is based on proportionate service acreage to be hooked up and 40 percent is based on proportionate flow at $45 per million gallons for those already hooked up. But only municipalities which have an access rights agreement with the county are obligated to pay the debt service. Of the 26 governmental units within Muskegon County, thirteen obtained access rights agreements.

The technical classification of the project was changed in 1971; this was to result in significant funding advantages. The original proposal as submitted to the Federal Water Quality Administration (FWQA) called for funding of 55 percent of the total eligible construction costs by state and federal agencies. Congressman VanderJagt, realizing that it was an untried system, worked with the FWQA and had the project classified as a "demonstration project," which allowed for funding of 75 percent of some additional costs. In 1973, the state and federal funding level for eligible construction costs was increased to 80 percent (55 percent federal and 25 percent state). Because the project was under the auspices of a demonstration grant, it was possible to institute a research and development program. The demonstration grant number is 11010GFS.

To finance the county's share of construction and land acquisition expenses, the board of commissioners authorized in 1971 the issuance of $16 million worth of public bonds to finance the local share of the construction costs and to pay for ineligible costs, which were principally land costs.

During the spring of the previous year, the corporate counsel of the board recommended that the Board of Public Works define and prescribe the land acquisition procedures to be used in the purchase of over 4,390 hectares (10,850 acres). Then, as monies became available through bond sales, the land acquisition officer would be able to immediately buy the parcels. This was done. The Board of Public Works hired an expert in land acquisition, knowledgeable in title and classification; they also hired appraisers, experienced condemnation attorneys, and a real estate brokerage firm as land acquisition officer. A title insurance company was engaged also. Where appropriate, all selections were done on a basis of submitted bids.

One of the most remarkable data in the history of the Muskegon County Wastewater Management System (WMS) is that the county was able to procure 85 percent of 425 parcels of real estate in seven months. This feat would not have been possible were it not for the passing of the Uniform Relocation and Land Acquisition Policies Act by the United States Congress. This law provided extensive financial benefits to dislocated persons in the form of additive payments supplementing the monies paid for their property, thereby enabling them to acquire excellent replacement housing. This law, which became effective January 1, 1971, provided that the U.S. Government would pay 100 percent of the relocation costs of land owners forced to relocate because of land acquisition, as long as these procedures were accomplished within 18 months of the law's effective date. The Board of Public Works selected a company and contracted out the relocation jobs. All land acquisition procedures were processed in accordance with federal guidelines, and the relocation company prepared and submitted its relocation plan to the Environmental Protection Agency (EPA). The acceptance of the plan meant essentially that one million dollars had been added to the WMS funding.

By the spring of 1972, over 85 percent of some 4,390 hectares (10,850 acres) was acquired. Appraisal of each parcel was presented before the county board, and the board authorized an offer through a purchasing agreement. The county board further offered an incentive bonus to the land acquisition agency of $20,000 if 85 percent of the purchases were accomplished within a specified time. The acquisition process went smoothly and quickly, resulting in only five fully contested condemnation cases out of some 200.

The approval of the final design in April of 1971 came after 9 months of intensive design work by Bauer Engineering, Inc. This period included an aborted attempt in December of 1970 to award a single large construction contract which included about 90% of the total project. Two very high bids were received—one of them twice and the other three times Bauer's estimate. In spite of the discouragement which this experience produced, a concensus was reached after much discussion that the project could be constructed within an acceptable budget if the work would be broken into many smaller construction contracts. It was the combination of these many smaller contracts which was approved in April of 1971.

The declaratory judgment lawsuit was tried in May, the bids were taken in May, the court decision became final in July, the $16 million in county bonds were sold in August, and construction began in September of 1971.

Through the stages of conception, planning, development, acceptance, and final approval of the Muskegon project, many valuable lessons were learned. In outline form, the crucial ingredients in the development of the project were:

1. Installation of a reorganized Muskegon County Board of Commissioners, (replacing the old Board of Supervisors), representing the entire county on a one-man, one-vote basis

2. The agreement of the four-state Lake Michigan Tributaries Conference with the FWQA and the assurance that funding priorities for clean water be on a regional rather than a municipal basis

3. Securing of bi-partisan support for the concept of land treatment through cooperation with Republican Ottawa County

4. Exertion of economic, social, and political pressures to achieve for the Muskegon project a higher priority level within the agencies of state and federal governments

5. Declaratory judgment in favor of the project as a result of the class action suit

6. Authorization of $16 million in bonds by the Muskegon County Board of Commissioners

7. Passage of the Uniform Relocation and Land Acquisition Policies Act which facilitated completion of land acquisition in a relatively short time

8. Actions of the board of commissioners and Congressman VanderJagt and other officials, elected and appointed, that were bold and courageous and supported an unpopular minority view

That aspect of the development of the WMS project from conception to construction which was least effectively handled was local public relations. Generally, public relations may be said to have suffered because of three problems:

1. The record of the Muskegon County Board of Supervisors in accomplishing county-wide projects was poor. The board's ineffective performance had produced distrust and profound lack of confidence on the part of the citizens.

2. Local newspapers and communication media were not in support of the project.

3. Education of the local population regarding the details of the operation was difficult because all through the planning stages changes were being made. The concept and design remained in flux over a long period, and to have tried to sell each and every component would have destroyed credibility. A more systematic approach toward informing the people of the developmental aspects of the system, as well as trying to convey the macroscopic importance to the future of the region, might have resulted in less local opposition.

The Muskegon County Wastewater Management System has two similar treatment sites. The major treatment site is the Muskegon-Mona Lake System which services the metropolitan Muskegon area (106 TCMD or 28 MGD). The smaller treatment site is the White Lake System which services the Whitehall-Montague area (3.8 TCMD or 1 MGD). See Figure 1. The main reason for planning two similar systems was that the White Lake area is located 32 kilometers (20 miles) north of the Muskegon metropolitan area, and it was not believed to be economical to install a transmission pipeline for 3.785 TCMD (1 MGD) from the north into the Muskegon-Mona Lake System. The information and all discussions in this report cover exclusively the Muskegon-Mona Lake System.

RESEARCH AND DEVELOPMENT PROGRAM

Because the Muskegon County Wastewater Management System was classified as a demonstration project, there has been an active research and development program associated with it financed primarily by EPA Research Grant No. 11010GFS. Of the $1.935 million allocated for R & D, 75 percent has been federally funded, and 25 percent has been from Muskegon County.

The following listing includes brief descriptions of each R & D activity in which the WMS has been active.

Monitoring of Surface and Groundwater Quality

The purpose of the surface and groundwater monitoring program was to establish background baseline physico-chemical characteristics of the waters before and during WMS operations and to evaluate possible effects of long-term and future operations.

Irrigation Rig Optimization Studies

The purpose of these studies was to gather information as a basis for the evaluation of different types of center-pivot spray irrigation machines and to prepare performance specifications for irrigation equipment with optimum efficiency on Muskegon soils. Also included were evaluations of aerosol winddrift under various operational and weather conditions.

Wells

The purpose of the construction and monitoring of the various series of wells was to facilitate monitoring of groundwater before and after WMS operations.

Management of WMS Farm Operations

The farm management program under the direction of the farm manager included all planning for initial agricultural activities and the subsequent development of a master farm plan to maximize the effective use of farm acreage.

Socio-Economic Studies

The purpose of these studies, done by Keifer & Associates of Chicago (formerly Bauer Engineering, Inc.), was to evaluate the impact of the WMS on the local economy. Included was the study of the WMS as a drawing potential for new industry into an area dependent largely upon the automotive industry.

Test Performance Studies

The purpose of this component was experimentation with the various operating modes of the WMS – including the living filter portion – in pursuit of maximum effectiveness with optimum efficiency. Details of how these various components were handled are in the treatment performance section.

Studies of Wastewater Use and Renovation by Soils and Crops

The purpose of these studies was to determine those crops best suited to local soils and to wastewater-irrigation-renovation; included were the evaluation of wastewater components on plant growth, studies of soil dynamics in response to wastewater irrigation, and the evaluation of crops as market items to reduce overall wastewater treatment costs.

Table 1 below itemizes each research and development component and gives the funding allocation.

Table 1. FUNDING OF WMS RESEARCH AND DEVELOPMENT COMPONENTS, 1972-1977

Project element	Duration	Funding
Surface and groundwater monitoring	1972-1977	$ 457,332
Irrigation equipment optimization (Pre-construction studies)	1972-1973	199,997
Wells	1972-1973	353,330
Farm management	1972-1977	172,014
Socio-economic studies	1972-1977	127,410
Treatment performance studies	1972-1975	355,530
Agricultural performance studies	1972-1976	213,148
Project administration	1972-1977	56,239
Total		$1,935,000

MANAGEMENT HISTORY

The Muskegon County Board of Commissioners sought professional business management for the WMS for several reasons:

1. The county board was strongly political and very partisan, but most important, the board was inexperienced in the management of an enterprise the magnitude of the WMS.
2. The opinion was held that to hire outsiders would present the opportunity of bringing together agencies of business and government.
3. Finally, it was believed that corporate ties might prove to be an asset in the improvement of the municipal bond rating.

Bids were taken. After a review, the county board selected Teledyne Triple R, a corporation with subsidiaries in the Muskegon area, as the managing firm for WMS, and a contractual arrangement on a fixed-fee basis was agreed upon. Teledyne Triple R (TTR) began to actively participate in the R & D program in the fall of 1971.

The early pre-construction studies were begun. An engineer was hired to canvass manufacturers of standard agricultural irrigation equipment and to establish specifications for purchasing prototypic irrigation rigs for evaluation within the WMS. A small staff was hired for the laboratory, and some laboratory equipment was bought in November, 1971. About the same time a cost accounting system was instituted.

In the spring of 1972, with a farm manager hired, work began on the setup of dry-land-variety corn test plots and test plots for other crops. As soon as the temporary laboratory was functional, monitoring was begun of surface and groundwaters, and the various pre-construction, equipment-optimization studies were begun with the purchase and setup of two prototype irrigation machines. During 1973, in addition to continuing the ongoing R & D programs, the first major planting was done: 607 hectares (1500 acres) of dry-land corn. Studies of the irrigation rigs were completed, specifications were drawn up, and the contract was awarded. The WMS staff was enlarging. Additional laboratory personnel were hired to handle the increased workload of the treatment performance studies, and TTR was hiring operators from wastewater treatment plants of surrounding communities as their systems were being phased out. Beginning in May, 1973, the WMS collection system, biological treatment and wastewater storage were operative.

In 1974, the first year of wastewater irrigation, about 1890 hectares (4700 acres) of corn were planted, but a combination of high water, relative unavailability of irrigation equipment and a poor growing season doomed the crop. Yields were poor. Simultaneously, Teledyne was suffering high turnovers of personnel in middle and high management. After three years of managing the system, the combination of capital outlay for equipment and poor crop yields had created a serious cash flow problem for Muskegon County. By late 1974 the operating deficit from the general fund was almost $1,000,000, notwithstanding the fact that TTR corporate headquarters had financed a large portion of the expenses of the beginning operations. It was clear that for mutual financial reasons the agreement between TTR and the county had to be terminated. This was done in December, 1974. The county assumed management of WMS.

The first year under county management was a success. With a good 1975 corn crop and lowered manpower requirements and other savings due to changes in operations, the operating deficit was reduced from almost $1,000,000 to $85,000. The county has retained management of the system to the present.

The preceding historical sketch has included the early planning and conceptual stages of the Muskegon County Wastewater Management System. In the sections to follow, these topics are discussed in detail:

Design

Irrigation Equipment Optimization Program

Operation and Maintenance

Treatment Performance

Monitoring of Ground and Surface Water Quality

Water and Materials Balance

Agricultural Productivity Studies

Management of Farming Operations

Socio-Economic Study

Economics

SECTION 2

CONCLUSIONS

The time required for the construction of this land treament project was brief: 85 percent of the parcels of land was acquired in seven months, and construction from groundbreaking to startup of operations was 20 months.

Within a closed flowing system such as the Muskegon project, it is possible to evaluate the effectiveness of wastewater renovation by the monitoring of water quality at various points along the continuum: the biological treatment cells, storage lagoons, chlorination, drainage pipes, outfalls to surface waters and groundwater wells. In Muskegon County the land treatment of mixed domestic-industrial effluent by the use of center-pivot irrigation machines produced, with some exceptions, discharge water of a quality which exceeded both design and NDPES standards for five-day biological oxygen demand, total phosphorus, suspended solids and fecal coliform.

Corn possesses several physiological attributes which make it a suitable crop for the heavy irrigation rates inherent to land treatment. Studies of nutrient levels in water, soil and crops revealed that the nitrogen, potassium and phosphorus applied during the 1975 irrigation season were retained to a significant degree in that soil layer available to the corn plants. By balancing the amounts of these nutrients in wastewater with crop needs, more efficient overall nutrient removal is achieved.

Remarkably high corn yields have been achieved on predominantly sandy soils. Healthy crop production is roughly equivalent to efficient nutrient removal and to reduced renovation costs. In 1975 farming income offset 39 percent of the operation costs of the system.

Depending on the influent wastewater characteristics, the operational mode of the biological treatment cells and storage lagoons may be manipulated so as to realize significant reduction in power consumption at considerable cost savings, without loss in water quality.

After three years of operation, no significant changes have been found in the water quality parameters of the groundwater. Those minor changes which have been detected in groundwater are thought to be due to factors extraneous to the water treatment operations. During this same period, there appeared to be an improving trend in some indicator parameters in the surface water quality.

Populations of game and other wildlife species have increased sharply in the project area.

There are indications that the presence of the wastewater project has been supportive in retaining local industries and in attracting new industries, thereby contributing significantly to the regional economy.

Total system costs in 1975 amounted to less than $28 per thousand cubic meters ($106 per million gallons), based on a daily flow of 106 thousand cubic meters (28 million gallons). This cost compares favorably with that of conventional treatment systems that often offer less complete renovation of wastewater.

A precedent has been set for municipalities to challenge private groups – such as environmental partisans – who seek to stop pollution control projects. The pioneering suit on behalf of the County against the Environmental Protection Organization of Muskegon County is a landmark.

Breaking of the construction work into a large number of separate contracts instead of letting the job all as one large construction contract saved very large sums of money.

SECTION 3

RECOMMENDATIONS

Of paramount importance to the understanding of wastewater renovation in a land treatment system are the various behavior patterns of the component pollutants after they are introduced onto the soil and crops by irrigation. Some mobile nutrients such as nitrate – if not adequately removed – may add significantly to the pollution of groundwater. The fate of nitrate in crop irrigation from the crop-root complex to leachate is poorly documented. Nitrogen mobility studies should be continued with different crops under varying conditions of soil permeability and crop planting density.

The roles of other pollutants, particularly organics and viruses, should be examined. The question should be resolved as to how the removal of these pollutants by land treatment compares with the efficacy of alternate treatment systems and to what degree the removal of organics and viruses by land treatment is consistent with requirements for environmental protection.

It is recommended that broad spectrum studies of overall energy input be initiated using a systems-analysis approach which would include use of manpower, electrical power and personnel for optimum project efficiency. The research should include computer modeling of lagoon kinetics and a re-evaluation of the monitoring program with the goals of immediate information retrieval for use in management decision-making. Included also should be studies of the response of soil cation-exchange-capacity to heavy irrigation. Knowledge of the time frame in which the cation-exchange-capacity may be expected to approach equilibrium would provide guidelines by which the future industrial expansion of the region might be intelligently influenced.

Because of the sparse information available on the application of the sludge within a sprinkler-irrigation system, studies should be done on the effects of such application on soil, crops and leachate.

Field equipment problems, such as nozzle-plugging on irrigation rigs, lightning damage to equipment and localized areas of inadequate drainage, should be corrected.

Because high density plantings may be expected to produce denser root matrices which should be more effective at nutrient recovery, experimentation with many corn varieties and with other crops should be continued, with customized nutrient fertigation according to the soil permeabilities. Denser plantings may produce higher crop yields for enhanced cost-efficiency. Included also would be expansion of the grain center drying and storage facilities to increase profits through more flexible marketing options.

Some industries and communities within the service area of the project remain without collection systems and continue to pollute surface waters. Those communities should be vigorously encouraged to install collection systems.

The construction of greenhouses with controlled temperature, humidity and light would make possible experiments during the winter months on various aspects of wastewater-soil-plant relationships.

SECTION 4

DESIGN

INTRODUCTION

The earliest design proposals were submitted in 1969 and were oriented toward handling relatively modest wastewater flow rates. But in June, 1969, with the decision of the S. D. Warren Paper Mill to join the county system, the design had to be altered to accommodate the additional flow of 60.6 thousand cubic meters per day (TCMD) or 16 million gallons per day (MGD). And with the subsequent expansion of the system to include surrounding townships and municipalities, the original construction cost estimates had tripled from $12 million to $36 million, and the estimated wastewater daily flow had increased from about 45.4 TCMD to 106 TCMD (12 to 28 MGD).

Bauer Engineering of Chicago predicted that this early design would service an area of 4,455 ha (11,000 a) in 1972 and about 12,150 ha (30,000 a) by the year 1990.[3] The projections are summarized below.

Table 2. BAUER ESTIMATES OF DOMESTIC-INDUSTRIAL PROJECTED WASTEWATER FLOWS IN 1972 AND 1990 IN THE MUSKEGON METROPOLITAN AREA

	Flow in TCMD		Flow in MGD[a]	
Wastewater source	1972	1990	1972	1990
Domestic	45.4	84.0	12.0	22.2
Paper mill	60.6	30.3	16.0	8.0
Total	106.0	114.3	28.0	30.2

[a] Please note that data are presented throughout the Introduction and Design in both metric and British units; thereafter metric units only are used.

At this early stage the prime considerations which were influential to design were the current and predicted characteristics of and volumes of wastewater being treated at existing facilities. A profile of those important characteristics is tabulated below, showing both the predicted loading of the treatment system in 1972 and in 1990, including the combined domestic and industrial effluents from the Muskegon metropolitan area.[3]

Table 3. ESTIMATES OF PARAMETERS OF WASTEWATER QUALITY FOR MUSKEGON METROPOLITAN AREA DOMESTIC AND INDUSTRIAL EFFLUENTS FOR 1972 AND 1990

	1972			1990		
	Concentration,	Rate,		Concentration,	Rate,	
	mg/l	kg/day	lb/day	mg/l	kg/day	lb/day
Five-day biological oxygen demand (BOD_5)	190	20,159	44,500	240	27,316	60,300
Suspended solids	181	19,253	42,500	235	26,636	58,800
Suspended volatile solids	141	14,949	33,000	184	20,838	46,000
Settleable solids	98	10,419	23,000	123	13,907	30,700
Phosphorus (P)	4.9	521	1,150	8.6	974	2,150
Nitrogen (N)	10.4	1,110	2,450	17.8	2,016	4,450
Sulfate (SO_4)	195	20,657	45,600	218	24,598	54,300
System flows	106 TCMD or 28 MGD			114 TCMD or 30 MGD		

Perhaps the most important single factor influencing design is the phenomenon of nitrogen removal from wastewater by soil and crops, for it is this factor which dictates the overall farmland area requirements and the selection of the crops for water renovation. Although the basic processes of crop assimilation, denitrification, nitrogen fixation, and nitrogen leaching to groundwater are individually fairly well understood, the total nitrogen mass balance within a soil profile has not been quantified nor well defined. For these 1969 proposals, it was intended that the principal source of nitrogen for the land being irrigated with wastewater would be from the wastewater itself. Thus, with the Bauer predictions of 10.4 mg/l in 1972 and 17.8 mg/l in 1990 in the wastewater entering the lagoon treatment system, it was possible to draw up a tentative mass balance for nitrogen as in Table 4.[3]

Data in Table 4 indicated that at an irrigation rate of 2.54 cm/wk (1 in/wk), the amount of nitrogen was insufficient for 1972 crop needs, and 5.08 cm/wk (2 in/wk) was adequate for a corn yield of 6.3 metric tons per hectare (100 bu/a). The predictions were that by 1990 the nitrogen content of the wastewater would be sufficient for crop needs with an application rate of just over 2.54 cm/wk (1 in/wk).

The original site selected for the WMS was in the Cedar Creek area, including part of Dalton Township, northeast of Muskegon, and it included 5,265 ha (13,000 a) for the initial development plus 1,620 ha (4,000 a) to be set aside for future use. The design called for the construction of lagoons for treatment and storage of wastewater and equipment for the irrigation of both agricultural and forestry crops, the distribution being estimated at 60 percent for agriculture and 40 percent for forestry. Figure 2 is a sketch of the proposed layout.[2] There were to be two treatment

Table 4. ESTIMATED 1972 MUSKEGON NITROGEN APPLICATION TO LAND AT WMS AND PROJECTIONS FOR 1990

	1972 - Applied to land					1990 - Applied to land				
	Conc., mg/l	at 2.54 cm/wk, kg/ha/yr	at 1 in/wk, lbs/a/yr	at 5.1 cm/wk, kg/ha/yr	at 2 in/wk, lbs/a/yr	Conc., mg/l	at 2.54 cm/wk, kg/ha/yr	at 1 in/wk, lbs/a/yr	at 5.1 cm/wk, kg/ha/yr	at 2 in/wk, lbs/a/yr
N applied to soil by irrigation water	8.3	58.9	66	118	132	14.2	100	112	200	224
N lost from soil to atmosphere	2.1	15.2	17	29.5	33	3.5	25	28	49.1	55
Net effective application	6.2	43.7	49	88.5	99	10.7	75	84	150	169
N from rainfall		5.3	6	5.3	6		5.3	6	5.3	6
Maximum N available to crops		49.0	55	93.8	105	80.3	90	90	156	175
N requirements of corn for yields of:										
215 kg/ha		89.3		89.3			89.3		89.3	
100 bu/a			100		100			100		100
Net excess (+) or deficiency (−)		−40.2	−45	+4.5	+5		−8.9	−10	+67	+75

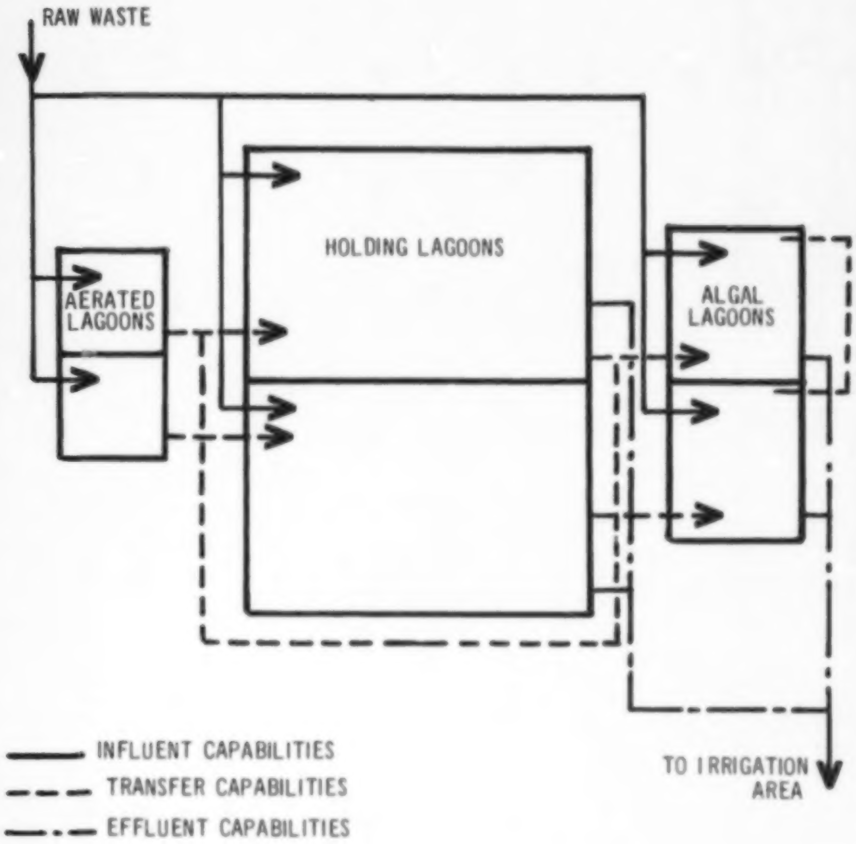


Figure 2. Early conception of lagoon treatment system

lagoons or aeration cells with treatment capacity of 113.6 TCMD (30 MGD), each with 2-day detention. They would be operable in either series or parallel. Each treatment lagoon was to be equipped with four 113.6 TCMD aerators rated at 44.7 kw (60 hp). The efficiency demand of the system required that at least 50 percent of the biological oxygen demand (BOD) be satisfied and that wastewater solids be maintained in suspension. The design required that a feed stream be maintained for the algal ponds.

This design called for two storage lagoons which would provide 120 days of detention at a flow rate of 74.0 TCMD (30 MGD). The total storage capacity was to be 12.3 million cubic meters (MCM) (440 million cu ft) at a depth of 6.1 meters (20 ft) and a total surface area requirement of 202.5 ha (500 a). The two photosynthetic ponds would accommodate 170 TCMD (45 MGD) average flow at 10 days detention; their depth was to be 1.52 m (5 ft) and their area 112 ha (276 a). These ponds, too, would be operable in either series or parallel. The photosynthetic ponds were to be equipped with mixers and aerators, and it was predicted that the designed operational flexibility would provide the desired algal productivity.

Water from this system was to be used for irrigation according to the regime outlined in Table 5.[3]

The site at Cedar Creek-Dalton Township was abandoned early in 1970 in favor of an area overlapping the townships of Moorland and Egelston, to the southeast of the original site. Selection of a second site was based primarily on the more uniformly highly permeable soils and the more uniformly flat topography, both features of paramount importance to successful irrigation. In September, 1970, after the selection of the second site, Bauer Engineering did a study for the FWQA entitled, "Engineering Feasibility Demonstration Study for Muskegon County, Michigan, Wastewater Treatment Irrigation System."[4] The work was initiated by the county board and its board of public works and the planning commission. The final report contained the important conclusion that to use lagoon treatment for wastewater and subsequently to use the wastewater for irrigation of crops was indeed feasible. Much of the information obtained in this study was to influence the design of the final system.

The report included essential background data from a program of analyses of wastewater samples from the sewage treatment plants of the Cities of Muskegon and Muskegon Heights, the resulting quality profile indicating that these wastewaters were typical of communities with mixed domestic-industrial sewage. But there was also evidence that occasional heavy industrial dumping had occurred, and this aspect of the report gave support to proposals for regulations dealing with sewer use throughout the region.

The report included analyses for heavy metals in Muskegon wastewater. The findings indicated concentrations sufficiently low that concern for the then current levels was deemed unwarranted. But it was recommended that a trace heavy metal monitoring program be established in order to detect possible future increases.

Other laboratory tests confirmed the effectiveness of treatment of combined wastewater of the City of Muskegon and S. D. Warren mill by the use of aerated lagoons. It was found that the five-day BOD was reduced an average of 70-90 percent within detention periods of two to four days. Other findings in this lab series were:

1. Chlorine demands of the aerated effluent were low; a chlorine dosage of 10 mg/l or less was adequate for disinfection.

2. Algae grew well in aerated effluent.

3. Sand column filtration showed significant reductions in phosphate, ammonia nitrogen and

Table 5. EARLY CONCEPTION OF ANNUAL HYDROLOGICAL OPERATIONS OF IRRIGATION SYSTEM

Month	Inflow,		Outflow,		Storage at start of month,		Irrigation rate			
							Forest 1620 ha (4000 a),		Agricultural 2430 ha (6000 a),	
	MCM	MG	MCM	MG	MCM	MG	cm/wk	in/wk	cm/wk	in/wk
Dec	3407	900	1768	467	1703	450	2.54	1.0	0	0
Jan					3342	883	0	0	0	0
Feb					6749	1783	0	0	0	0
Mar			1768	467	10155	2683	2.54	1.0	0	0
Apr			3940	1041	11794	3116	2.54	1.0	2.29	0.9
May			3940	1041	10719	2832	2.54	1.0	2.29	0.9
Jun			3940	1041	10719	2832	2.54	1.0	2.29	0.9
Jul			5390	1424	10182	2690	2.54	1.0	2.29	0.9
Aug			5390	1424	8198	2166	2.54	1.0	3.81	1.5
Sep			5390	1424	6211	1641	2.54	1.0	3.05	1.2
Oct			4667	1233	4224	1116	2.54	1.0	3.05	1.2
Nov			4667	1233	2964	783	2.54	1.0	3.05	1.2
Dec			1768	467	1703	450	2.54	1.0	0	0

color; phosphate was less than 0.1 mg/l; ammonia nitrogen was reduced 50-75 percent; and color was at less than five units.

In order to simulate the operation of the storage lagoons under conditions of varying irrigation rates, a mathematical model was constructed into which was fed local climatological data from the years 1948 to 1969 and water quality data from hypothetical storage lagoons. Using, on the one hand, a range of 3.8 to 6.4 cm/wk (1.5 to 2.5 in/wk) for irrigation and, on the other hand, no irrigation during freezing and precipitation periods, the requirements of the storage lagoons varied between 14.53 MCM at 0.121 MCMD for four months (3840 MG at 32 MGD for four months) and 18.17 MCM at 0.121 MCMD for five months (4800 MG at 32 MGD for five months). The hypothetical irrigation area for the model was 3,848 ha (9,500 a). Such simulation experiments made the model an excellent tool for the modification and refinement of the final design of the water treatment system, and, later, the same model was to be of help in sketching out various operational guidelines.

The early investigations into soil profiles and groundwater tables at the Moorland-Egelston site indicated that two techniques would be necessary to monitor and manage groundwater movement: a system of drainage pipes and a system of drainage wells. It was determined that spacing between drainage wells should range between 244 and 1,372 meters (800 and 4,500 ft); spacing between drainage pipes should range between 61 and 457 meters (200 and 1,500 ft). A more detailed description of the groundwater management system appears later in this section.

The agricultural aspects of the engineering feasibility study included the following recommendations for land use:

1. Sod production
2 Perennial grasses; *i.e.* hay or pasture
3. Christmas tree production in specific areas
4. Beef cattle production

At the conclusion of the report, the following courses of action were suggested to the county board:

1. Proceed with the design and construction.
2. Develop a research and development program.
3. Expand the agricultural studies, and review the potential of commercial agricultural opportunities.

Design work began in August of 1970 and was completed in March of 1971 for the majority of the project for which bids were taken in May of 1971. Later aspects of the design which continued and for which bids were taken later included the irrigation rigs.

The designs proposed by Bauer Engineering were judiciously and expeditiously reviewed by both state and federal agencies, with some modifications resulting from the review processes. About 90% of the construction plans and specifications were approved in April of 1971. Later approvals of the remaining items came in 1972.

ENVIRONMENTAL IMPACT STUDY

On June 21, 1971, the Office of Water Programs, Region V, submitted an environmental impact statement for the Muskegon County Wastewater Management System No. 1 to the Council on Environmental Quality. The following is a summary.[5]

Short- and Long-range Uses of Environment

This project constitutes an attempt to reach beyond the short-range marginal action common to many present wastewater management efforts. In fact, support for the project is based on its performance capability to facilitate realization of long-range environmental goals and development opportunities of the region and at a cost comparable to that being incurred by other areas for short-range environmental measures. The project will easily protect all impact areas for the highest water resource use designations now in effect.

More important is the fact that the treatment system can achieve virtual total removal of a more extensive group of problem constituents in the waste than present regulatory programs require. As a result, it will also be in a better position to meet the more restrictive and broader-based performance standards that may be implemented in the future.

Commitment of Resources

Although the project entails the commitment of a large land area for lagoon treatment and land irrigation, this commitment is not an irretrievable one. The land will not be degraded in the process of irrigation but will be improved in fertility.

As the technology of waste treatment develops and other alternatives become available, or if it becomes more desirable to use this land for other agricultural purposes, it can be readily redirected into such use.

It seems apparent, however, that the inland area will always be a preferred location for the performance of waste treatment activities. The shoreline land area adjoining the prime water resource units have a much greater potential beneficial use for a higher level of cultural activity.

Public Objections to the Project

The Muskegon County Wastewater Management Plan was adopted unanimously by the Muskegon County Board of Commissioners in May, 1969. Resolutions of full support and participation were passed by each of the 13 governmental contractees in the fall of 1970. The overall community support was demonstrated by signed contracts between the county and each participating governmental unit and by the public support of the service agencies in the county.

Certain local concerns and objections to the project were raised by citizens who were living in the project site area and by citizens living in the adjacent areas outside the site boundaries.

These concerns were due in part to apprehension over obtaining a fair price for property sold to the county but were also due to a lack of understanding by individual citizens of the performance capability of the system. And there was a general apprehension about a project of this magnitude being built near individual residences. Specific aspects of local conceptual difficulties include:

1. Difficulty in understanding how an area that presently experiences high groundwater levels for part of the year can be beneficially irrigated

2. Lack of understanding of how the sub-drainage system prevents out-migration of percolate and effectively manages groundwater levels

3. Concerns about potential odor and other nuisance problems

4. Concerns about the possibility of aerosol spray from operation of the irrigation system; such a spray is prevented from migrating out of the project area by using low-pressure, large-droplet irrigation, by avoiding irrigation during exceptionally windy days, and by the development of tree buffer zones around the perimeter. Effluent disinfection before irrigation provides an additional level of protection.

Figure 3 shows a schematic plan of the elements of the Muskegon system after final revisions of the design were completed and represents the system as it is today. Figure 4 is an overall aerial view.

DESIGN BASIS

As mentioned earlier, the primary design goal of the WMS planners was to meet or exceed the requirements of local, state and federal agencies for clean water to be achieved by land treatment, while simultaneously aiming at secondary goals of improving the overall environment in ways which would boost the regional economy. In the decision to build the project at the Moorland-Egelston site, there were many and diverse inputs into the design conspectus. Among those considerations were:

Geographic Location

Muskegon County is located on the eastern shore of Lake Michigan about 185 km (115 mi) north of its southern tip. The county is traversed by many streams which flow predominately westward and converge eventually into one of three inland lakes: Bear Lake, Mona Lake, and the largest, Muskegon Lake. The WMS site is 24 km (15 miles) east of the Lake Michigan coastline and is drained by two stream systems, the Black Creek to the south and the Mosquito Creek to the north. Treated wastewater which is channeled into these creeks flows to Mona and Muskegon Lakes and finally to Lake Michigan. See Figures 1 and 5.

Climate

The climate of the area is tempered by the position of the county relative to Lake Michigan. Precipitation, including snow, averages 76.2 cm/yr (30 in/yr) and is considered moderate; of the 218 cm/yr (86 in/yr) of snow, most falls during December and January. The mean average annual temperature is 8.4°C (47.2°F) with the average maximum in July at 26.8°C (80.3°F) and the average minimum in January at -8.0°C (17.6°F). The average frost-free period ranges from 160 to 170 days.

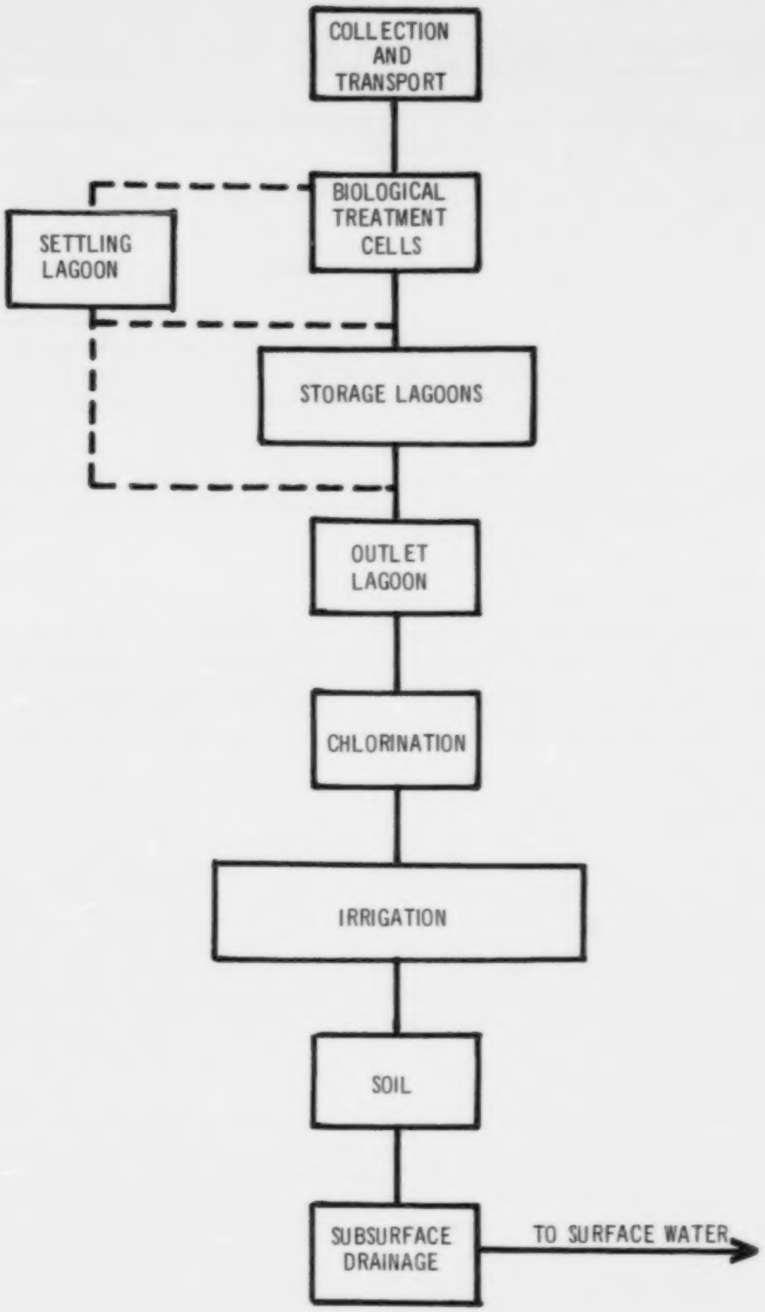


Figure 3. Schematic flow of Muskegon Wastewater System

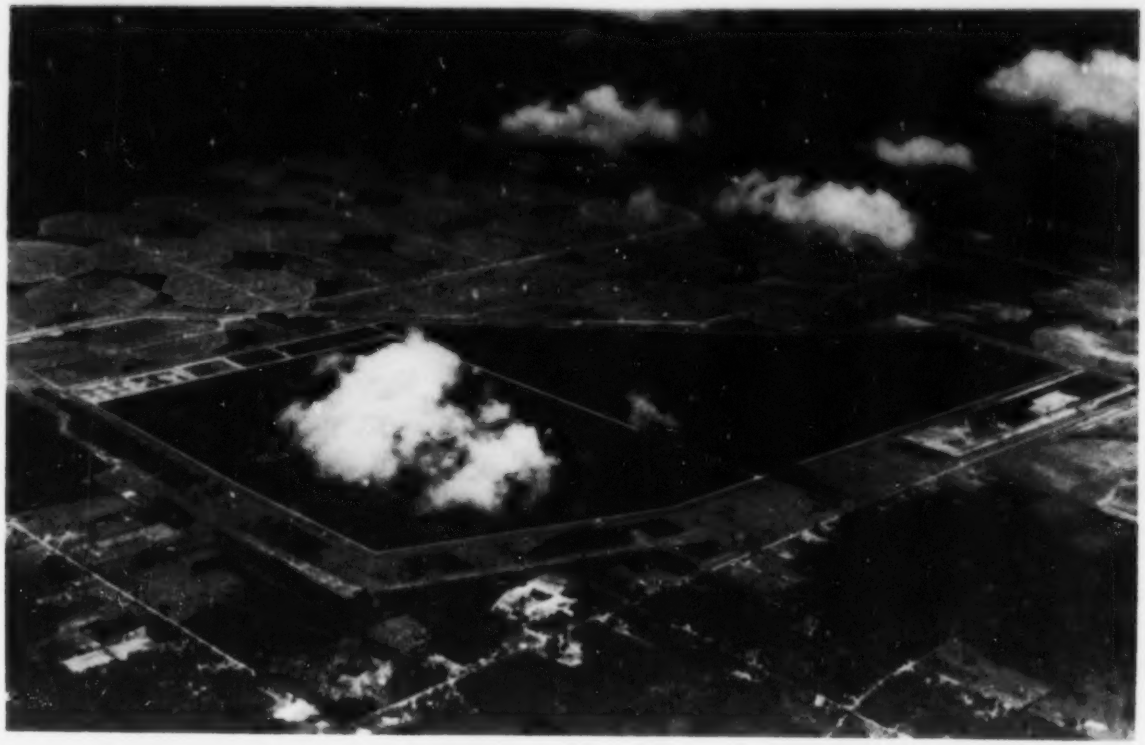


Figure 4. Aerial view of wastewater site showing irrigation circles beyond the impoundment lagoon

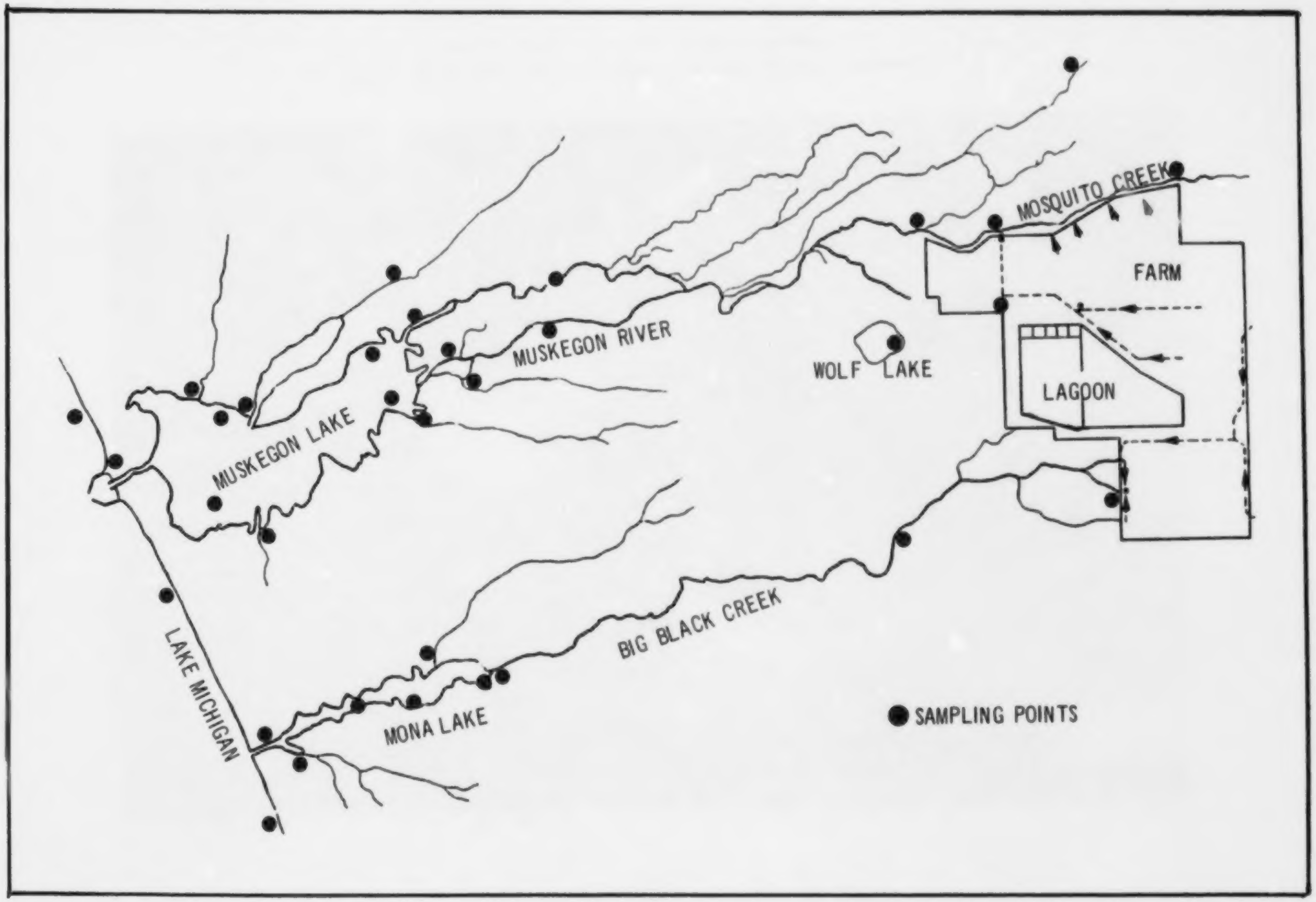


Figure 5. Surface water drainage from irrigation site with sampling points

Final Site Selection

The reasons for selection of the Moorland-Egelston site were:

1. It was a large area of relatively unproductive, unpopulated land, and it was available.
2. The distance from the major effluent sources was 16-19 km (10-12 mi), considered moderate.
3. The low population density of the area – about 5 residents per square kilometer (13 per sq mi) – lowered relocation expenses.
4. The land had low market value.
5. The site was located on a flat outwash plain with slopes ranging from 0-6 percent, thereby reducing runoff and erosion problems.
6. The soils of the area are sandy and have characteristically high permeabilities.
7. The potential of the site for multiple land use was high.
8. Only about 50 percent of the land required clearing operations, primarily for the removal of scrub oak.

In an overall view of these site considerations, perhaps the most important single criterion was soil permeability: it is this feature of soil which largely determines the amount of land required to treat a given volume of wastewater, and because of the abundance of sandy, highly permeable soils at the WMS site, a relatively modest land area 4,455 ha (11,000 a) was recommended.

Besides the areas covered with scrub oak, there were patches scattered with scotch pine, jack pine, aspen, ash, lowland hardwoods, white pine, oaks, and open grassland. See Figures 6 and 7. Prior to the clearing of the land, there were small populations of whitetail deer, cottontail rabbit, ruffed grouse and ring-necked pheasant. With the establishment of the lagoons and farm crops, large numbers of waterfowl and shoreline birds were predicted, and increases in the population of other wildlife species were also expected. Wildlife management through controlled hunting was suggested for the site.

Multiple Use Opportunities

A solid waste site was constructed on the grounds. The design of the site included features designed to maximize groundwater control, so leachate from the solid waste area might be collected, pretreated if necessary, and pumped into the storage lagoons. Absolute groundwater control has not as yet been achieved, however.

Among the multiple-use ideas were suggestions for various recreational activities and for the construction of an industrial park at the site. Such industries might use lagoon water for supplementary cooling purposes, and there would be the advantage of proximity to the facility for treatment of their own wastewater.

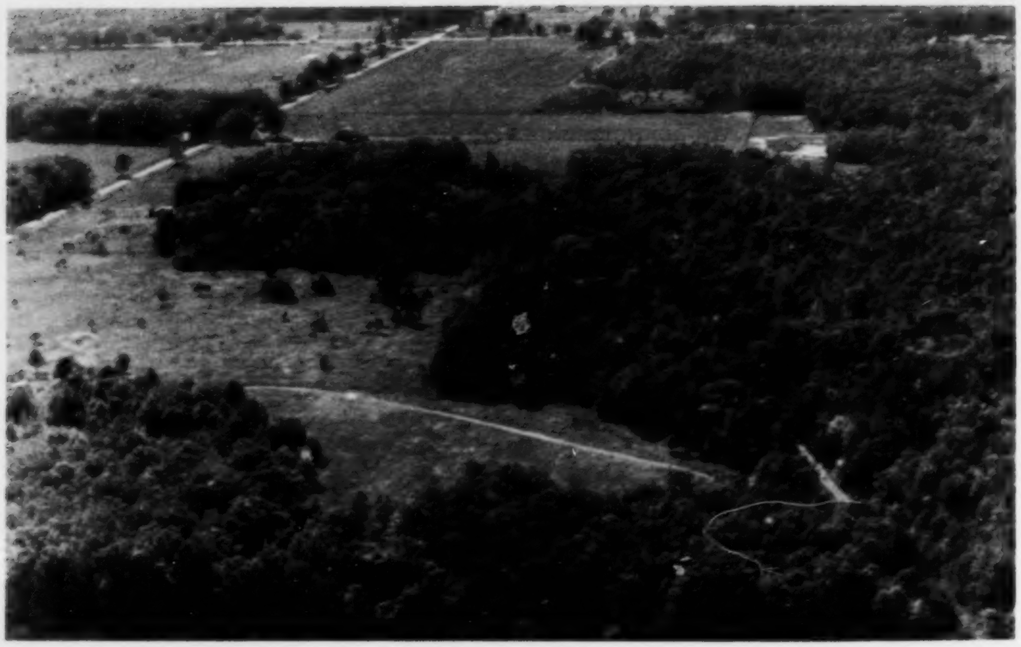


Figure 6. Project site north of Apple Avenue, September, 1971

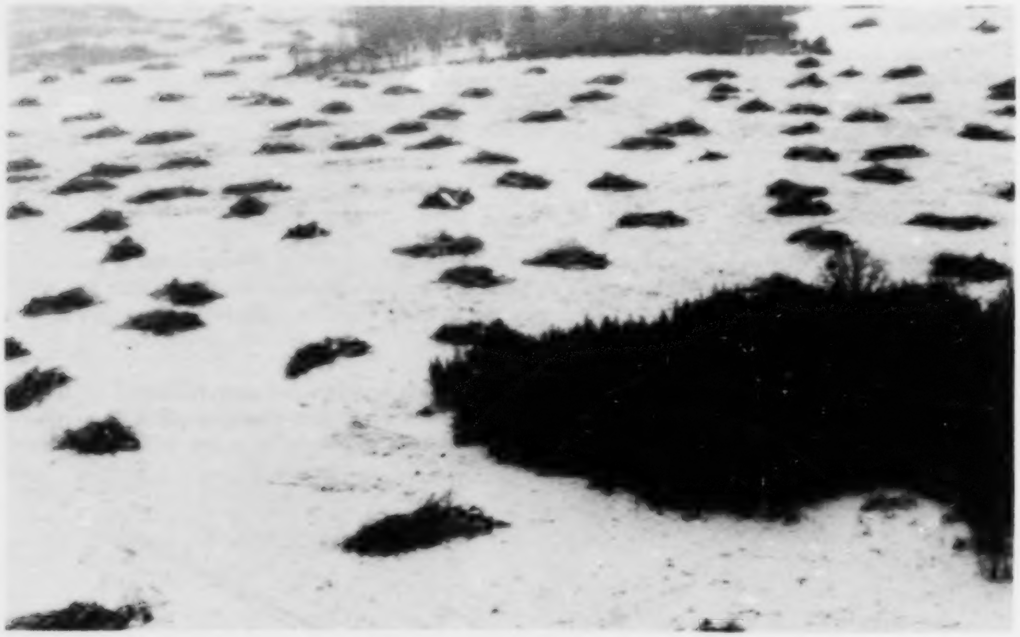


Figure 7. Stacks of bulldozed trees in early clearing operation

PHYSICAL DESIGN OF THE SYSTEM

Wastewater Flow Projections

Projections of effluent flow rates were estimated based upon population growth and service area extensions, projected development of industrial and commercial parks, present industrial flows already connected to the system, and industrial flows proposed to be connected to the system. According to the Muskegon County Planning Commission and the 1970 Preliminary U.S. Census Report, the present and projected population growth and service area growth are as follows:

1972 Estimate		1992 Design Estimate	
Population	Service area	Population	Service area
140,000	50,625 ha (125,000 a)	182,000	65,205 ha (161,000 a)

The present major municipal contributors are the Cities of Muskegon, Muskegon Heights, North Muskegon, and Roosevelt Park, with an average unit flow rate from these domestic sources of 0.341 cubic meters/capita/day (90 gallons/capita/day) and a peak of 0.757 cubic meters/capita/day (200 GCD). The major industrial contributors are the S.D. Warren Paper Mill and the Story Chemical Company. Table 6 lists the effluent contributors to the WMS with the average daily flow of each.[3]

Table 6. ESTIMATED 1972 EFFLUENT CONTRIBUTOR FLOW RATES

Contributor	Flow in TCMD	Flow in MGD
Domestic sources in Muskegon metropolitan area	45.4	12
S.D. Warren Paper Mill	30.3-60.6	8-16
Story Chemical Company	3.8	1
Continental Motors	1.9	0.5
Other industries	1.9	0.5
Total flow	113.6	30.0

In Table 7 below, data from the preliminary studies conducted by Bauer Engineering, Inc., provide a comparison of 1972 average flow rates from the domestic and industrial sources with the average and peak flow rates projected for the year 1992.[3]

Table 7. ESTIMATED FLOW RATES IN 1972 AND 1992 FOR DOMESTIC AND INDUSTRIAL EFFLUENTS

	1972		1992				
Source	Avg TCMD	Avg MGD	Avg TCMD	Avg MGD	Peak TCMD	Peak MGD	Percent of total
Domestic	28.4	7.5	60.6	16.0	151	40.0	38.0
Mixed industrial and commercial	16.7	4.6	17.4	4.6	43.5	11.5	11.0
Special industrial	62.5	17.2	51.1	13.5	65.1	17.2	32.0
Special development	0	0	29.5	7.8	74.2	19.6	19.0
Totals	107.6	29.3	158.6	41.9	333.8	88.3	100.0

Wastewater Characteristics

The composition of the wastewater treated at WMS is by volume about 40 percent domestic and about 60 percent industrial in origin. The total effluent has a calculated population equivalent of 300,000. A profile of select characteristics of this wastewater is in Table 8 below.

Nutrient concentrations in effluent have obvious implications for design, including lagoon dimensions, rate of wastewater application to soil and crops, and soil-crop removal rates. It is known, for example, that phosphorus complexes heavy metals in soil, and, of course, the efficiency of nitrogen removal from effluent varies significantly with the amount applied to the crop. These interactions of effluent nutrients with soil and crop are discussed in more detail in the treatment performance section.

The wastewater profile in Table 8 was done by Bauer Engineering and indicates their predicted effectiveness of the WMS system.

Table 8. WASTEWATER CHARACTERISTICS OF WMS INFLUENT AND PREDICTED DESIGN EFFECTIVENESS

Item	Muskegon-MonaLake, Number/100 ml	Influent, mg/l	Effluent, mg/l	Effective removal, percent
BOD	-	250	4	98-99
Suspended solids	-	250	4	98-99
Phosphorus	-	5	0.5	83-90
Nitrogen (Total N)	-	20		
Ammonia-N	-		0.5	97-98
Nitrate-N	-		5.0	75-87
Coliform bacteria	$2\text{-}20 \times 10^6$		0	100
Pathogenic viruses	(Known to be present in undefined concentration)		0	100

These flow projection data in combination with wastewater chemical profiles and soil characteristics influenced design specifics such as lagoon loading tolerances and design generalities such as the overall size and kind of wastewater renovation facility that would be built in Muskegon County.

Collection, Treatment and Storage of Wastewater

An average of 106 TCMD (28 MGD) of wastewater is conveyed to the WMS by a collection network of force mains, pumping stations and gravity sewers which arborizes from the site to the various domestic and industrial sources. See Figure 8. Along the pipeline-sewer network which connects the many discharge points with the treatment facility are 13 pumping stations (or lift stations) equipped with vertical, non-clog sewage pumps. Wastewater is impelled from the lift stations to the site by the central pumping station in downtown Muskegon. This station has a maximum pumping capacity of 212 cubic meters per minute (CMM) (80.6 MGD) and is linked to the treatment site 17.7 km away (12 mi) by reinforced pipe 1.68 m (66 in) in diameter.

As wastewater arrives at the treatment site, it is first biologically treated in one or more of three aeration lagoons, which are essentially adjacent ponds of 3.24 ha (8 a) surface area each and which, depending upon seasonal conditions, may be operated in series or in parallel. See Figure 9. The aeration lagoons have sloping walls lined with concrete and bottoms lined with soil-cement, and with a water depth of 4.9 m (16 ft) and a freeboard of 1.2 m (4 ft), they have a treatment capacity of 159 TCMD (42 MGD). Each treatment lagoon is equipped with 12 mechanical floating aerators rated at 44.7 kw (60 hp) each, and each has a transfer capacity of 1.78 kg/hr/kw (2.75 lb/hr/hp), or 75 kg O_2/hr each (165 lb/hr), and six fixed turbine mixers rated at 37.24 kw (50 hp) each. See Figure 10. Once biological treatment in these lagoons is completed wastewater is discharged into either of two storage lagoons. These large lagoons serve several functions: they provide a large reservoir of water for the irrigation season; they constitute a holding area in which suspended solids in wastewater may settle out; and, depending upon the duration of retention of the water, they facilitate the breakdown of toxic materials and pathogenic microorganisms.

The combined storage capacity of the two lagoons is 19.3 million cubic meters (5.1 billion gal). Each covers an area of 344 ha (850 a), or a combined area of 6.88 square kilometers (2.66 sq mi), with a solids storage depth of 60-90 cm (2-3 ft) and a water storage depth of 2.7 m (9 ft) with 90 cm (3 ft) of freeboard. At a flow rate of 159 TCMD (42 MGD), the total storage capacity is designed for about four months. The dikes surrounding the lagoons are 4.6 m high and 60 m wide (15 ft by 200 ft) at the base with side slopes of 4:1 interior and 3:1 exterior. With a 20 cm (8 in) layer of soil cement, the dike and clay lining together provide at least 183 m (600 ft) of horizontal filtration. See Figure 11.

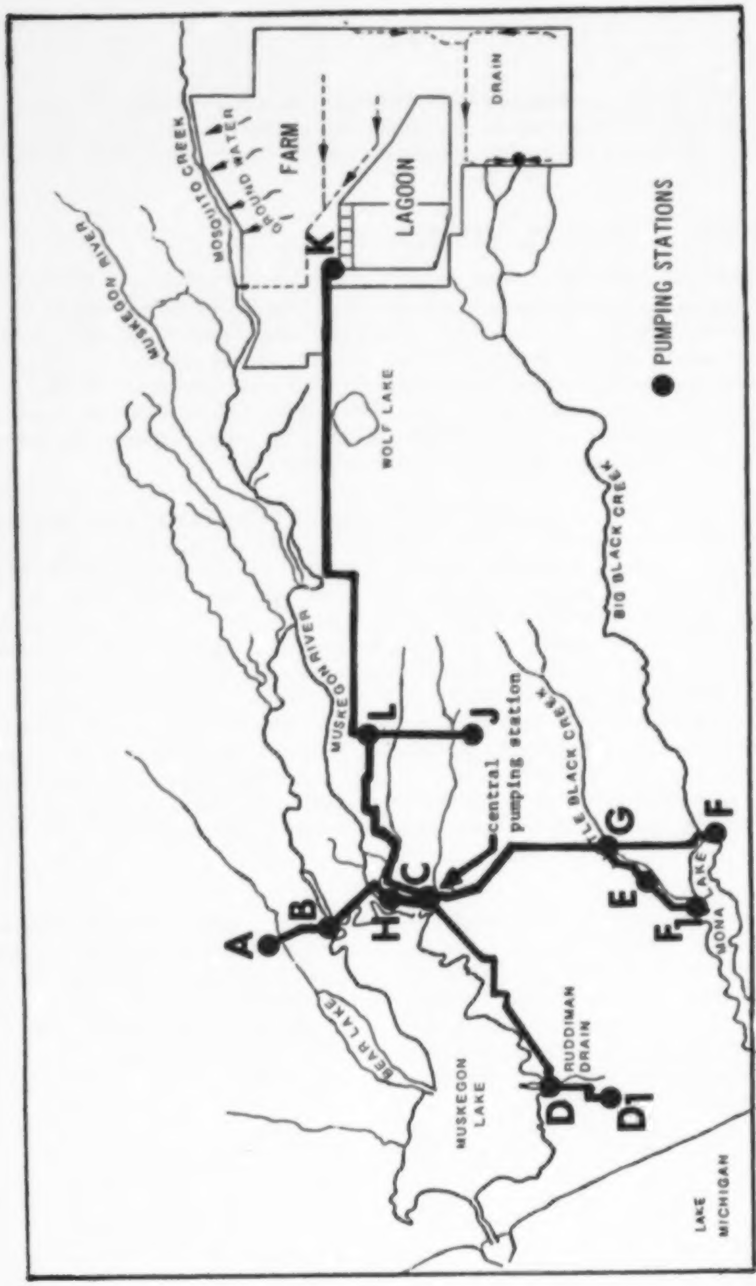


Figure 8. Collection Transmission System

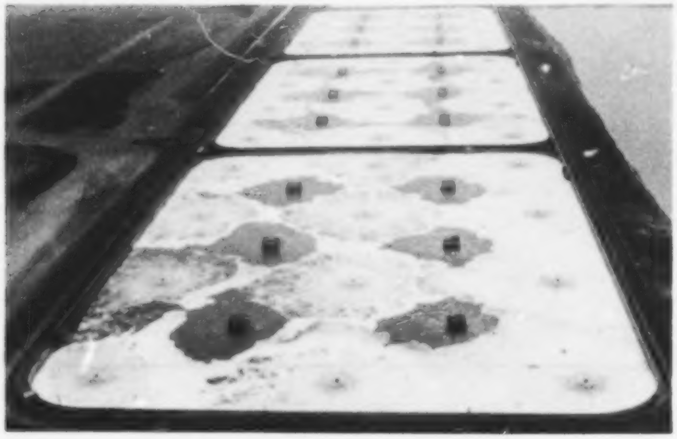


Figure 9. Biological treatment cells in operation with the west storage lagoon on the right

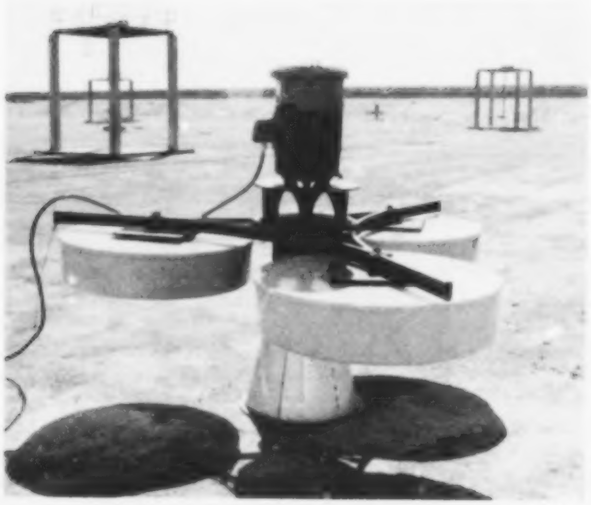


Figure 10. Aerator in biological treatment cell with mixers in background

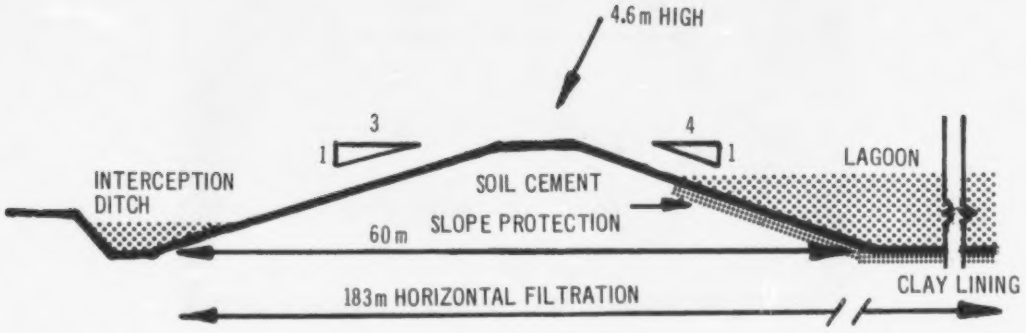


Figure 11. Cross section of dike (not to scale)

Surrounding the storage lagoons are interception ditches which are designed to catch leachate from the lagoons as well as to create a small hydrologic gradient in the groundwaters toward the lagoons. This leachate – or seepage water – is monitored for water quality on a daily basis, and as it meets the standards of the Michigan Department of Natural Resources, it is pumped directly into the nearby receiving streams. See Figure 12. Otherwise, it is pumped back into the lagoons. Such pumping in either direction is done by two pumping stations, each equipped with three 55.9 kw (75 hp) pumps rated at 32.7 TCMD (8.64 MGD), and each station pumps between 30 and 57 TCMD (8-15 MGD), depending upon the hydraulic head exerted by the lagoons.

As an adjunct to the three aeration lagoons or cells and the two storage lagoons, there is a separate settling lagoon which shares essentially the same engineering specifications as the aerator lagoons. After biological treatment, the wastewater may pass through the settling lagoon in order to settle out additional solids so that it may be used directly for irrigation during periods of peak water demand. Wastewater in this lagoon bypasses the storage lagoons. See Figure 3.

Water to be used for irrigation may be drawn from either of the storage areas or from the settling cell into yet another lagoon designated as the outlet lagoon, which has a surface area of 5.67 ha (14 a) and a water depth of 3.66 m (12 ft). It is as the water exits from this outlet lagoon that it passes through a chlorinator and is disinfected. The chlorination unit is equipped with two evaporators, each with a maximum capacity of 2,730 kg/day (6,000 lbs/day), or a total of 5,450 kg/day (12,000 lbs/day), which provides 14.4 mg/l at a wastewater flowrate of 378 TCMD (100 MGD).

From the chlorinator the wastewater passes through two open channels to the north and south irrigation pumping stations. Water monitoring has indicated that almost no residual chlorine remains after it reaches the stations. Water going into the north irrigation channel travels at a maximum velocity of 75 cm/sec (2.5 fps) with a minimum residence time of 29 minutes in the 1,210 m (3,970 ft) channel. The channels are lined with 0.05 mm (0.02 in) PVC and covered with 10 cm sand to protect the liner from UV light. The minimum residence time of water in the south irrigation channel, which has a length of 2,890 m (9,480 ft), is 60 minutes, again with a maximum velocity of 75 cm/sec. In either channel the maximum rate of water movement is 189 TCMD (50 MGD).

The Irrigation System

The total land area irrigated is 2,200 ha (5,500 a). With an irrigation season of 8 months or 240 days—which includes application of water to the land before, during and after cropping—the average weekly application rate including rainfall is 9.5 cm (3.8 in), according to design specifications of Bauer Engineering. This rate takes into account the total annual water balance based upon a design flowrate of 159 TCMD (42 MGD) for 365 days, or 58,250 TCM (15,300 MG) of wastewater.

Handling these volumes of wastewater is an irrigation system which is comprised of four subsystems:

1. Pumping stations
2. Distribution pipelines
3. Center-pivot irrigation rigs
4. Groundwater and subsurface drainage system

Pumping Stations

Each of the two irrigation channels which receive chlorinated water is equipped with a pumping station, and each station has two manifolds. See Figure 12. The 21 pumps in these stations are of the vertical turbine type, and the various ratings and capacities for each are tabulated in Table 9 below.

Table 9. SPECIFICATIONS ON VERTICAL TURBINE PUMPS IN IRRIGATION PUMPING STATIONS

Station	Manifold	Number of pumps	Pump Capacity, TCMD - TDH[a] (m)	Pump Capacity, MGD - TDH (ft)	Total Capacity, TCMD	Total Capacity, MGD
North	S	5	19.9 at 60	5.27 at 198	99	26.2
	N	5	23.3 at 65	6.16 at 212	118	31.2
South	S	7	23.8 at 63	6.30 at 208	167	44.1
	N	4	10.4 at 49	2.75 at 162	42	11.1

[a] TDH = total discharge head.

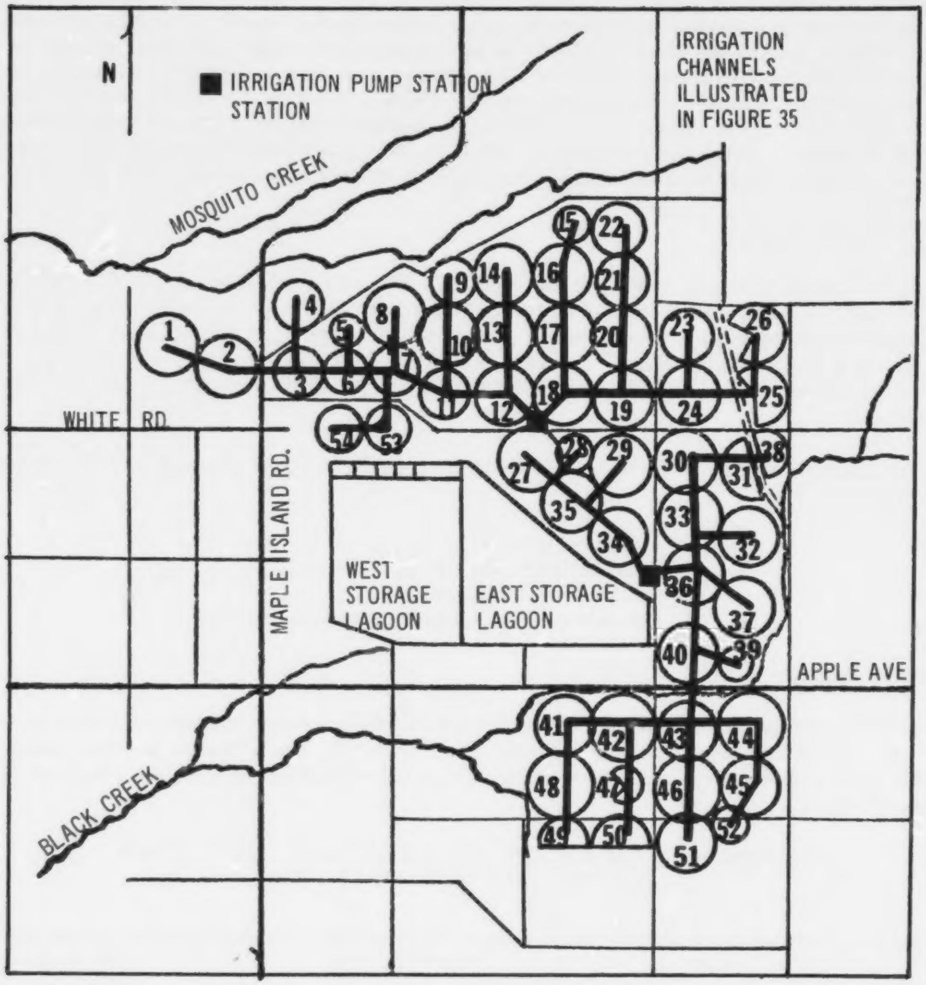


Figure 12. Pressure pipe distribution for irrigation

Distribution Pipelines

The network of pipelines for distribution of irrigation wastewater consists of about 37.5 km (25 mi) of asbestos-cement pipe, which ranges in size from 90 cm (36 in) diameter at the points of connection to the pumping station manifolds to 20 cm (8 in) diameter at the most remote ends of the lateral lines. See Figure 12. These pipelines had strength requirements which specified that transite pipe be used with pressure tolerances of not less than 13.3 kg/cm^2 (190 psi) and that lines be buried to a depth of 2.4 m (8 ft) in Class C bedding. The actual burial depth, however, turned out to be 1.2-1.5 m (4-5 ft). The pressure tests performed on the system went up to 8.8 kg/cm^2 (125 psi), but in normal operation the pressure of irrigation water does not exceed 5.3 kg/cm^2 (75 psi).

Throughout the pipeline network, air relief valves were installed at the points of highest elevation and ball valve drains similarly at the low points.

Center-Pivot Irrigation Rigs

The farm site has a total of 54 irrigation circles covering an area of 2,200 ha (5,500 a), all of which is irrigated by giant, center-pivot irrigation rigs. Each rig has a spray bar of a diameter of 7.5 cm (3 in) and of a range in length from 210-420 m (700-1,400 ft), covering a corresponding range of area of 14-56.6 ha (35-141 a) each, depending upon the length of the spray bar. See Figure 13. Along the lengths of the spray bars are spaced nozzles with orifices of diameter from 0.31-0.62 cm (1/8-1/4 in). The mobile, spray-bar-armature structures are supported from central towers by truss-type suspensions, and the armatures are powered by shaft-driven electric motors housed within the central towers, or pivot points. See Figure 14. As they move around the central pivots, the rigs ride on regularly spaced rubber tires; the size of tires specified were 14.0 x 24.

The maximum water delivery capacity per rig is 7.6 TCMD (1.94 MGD), and the minimum hydraulic pressure within the pipeline at the pivot point is estimated at 2.5 kg/cm^2 (35 psi).

Groundwater and Subsurface Drainage System

Pre-construction geological and hydrological studies of the WMS site revealed that in extensive sections of the south and east site area groundwater depths of less than 1.5 m (5 ft) were common. In general it was found that groundwater depths increase to more than 7.6 m (25 ft) as one moves north and west across the site. Groundwater inflow was found to occur primarily along the eastern boundary and secondarily along the portion of the southern boundary, whereas the main patterns of outflow were toward Mosquito Creek and Big Black Creek. The results showed a typical transmissibility of 250 CMD/M (20,000 gpd/ft) of width under a unit hydraulic gradient, in spite of a variation of sand thickness from a maximum of about 48 m (160 ft) to a minimum of about 6 m (20 ft). The storage coefficient appeared to be about 10 percent.

The drainage system was thus provided:

1. to intercept the water which would percolate through the soil as the result of the wastewater and precipitation which would infiltrate into it,

2. to keep the zone of soil moisture thick enough – a minimum of 1.5 m (5 ft) was desired – so that there would be good plant growth and thus good uptake of nutrients in the wastewater,

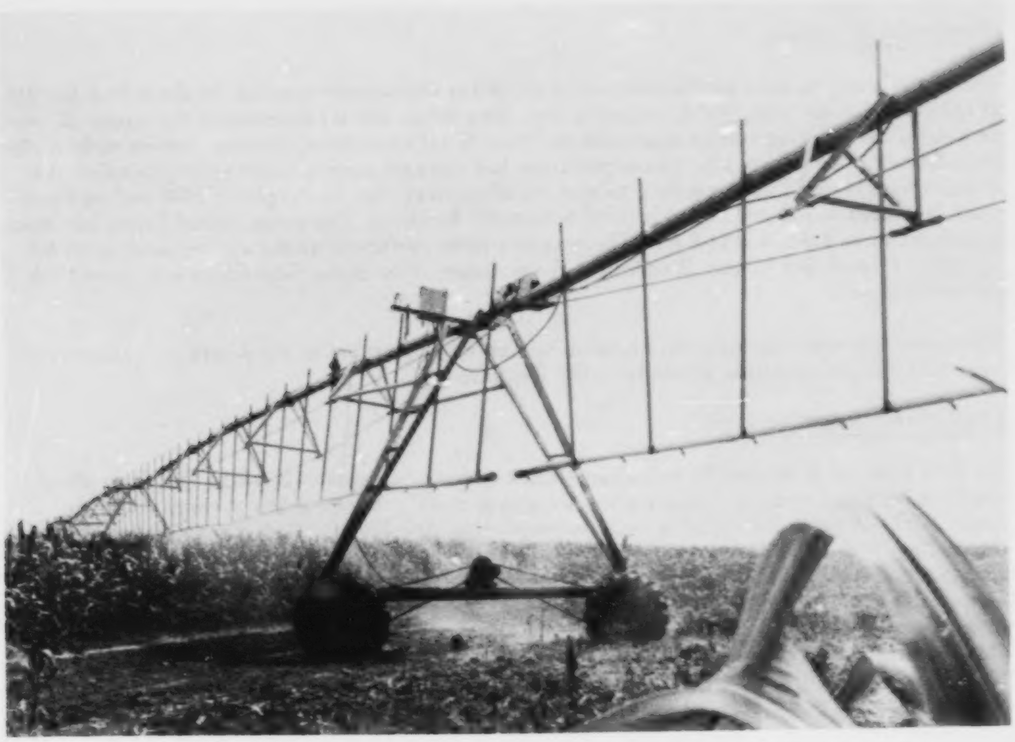


Figure 13. Lockwood irrigation rig in operation over corn

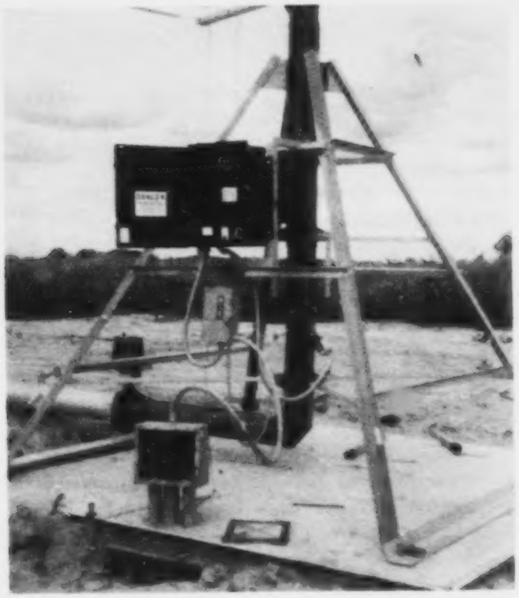


Figure 14. Center pivot of rig with control panel and power supply

3. to produce a slight hydraulic gradient into the site from the surrounding lands outside the boundaries of the project site, thus preventing migration of groundwater out of the site.

The third objective was facilitated by the naturally high groundwater levels throughout much of the site prior to construction. High groundwater levels in a proposed wastewater irrigation site prior to construction are an advantage if one is required to prevent outward migration of groundwater from a proposed site.

There was constructed a subsurface drainage network which consists of systems of drainage pipes, wells, and ditches which collect and convey renovated water to nearby surface streams. The man-made components consist of 35 wells, 105km (70mi) of perforated drain pipe, 29km (19mi) of solid drain pipe, and 15km (10mi) of drainage ditches. See Figure 15.

Of the 2,200ha (5,500a) under irrigation, the majority is drained by perforated drain pipe made of corrugated polyethylene enclosed in fiberglass filter sock. The final design adopted the 15cm (6in) pipe as the standard pipe to be used throughout the project, supplemented with small quantities of 20cm (8in) and 25cm (10in) diameter pipe in selected laterals. The pipes were buried at a minimum depth of 1.5m (5ft) and a standard slope of 0.4 percent. With a Manning n of 0.02, this pipe would then handle up to 0.007 cu.m/sec (0.24cfs) at an average velocity of 0.36m/sec (1.2ft/sec). With a standard spacing of 152m (500ft) and a typical length of 460m (1500ft), such a pipe would drain an area about 6ha (17a) at 0.8cm/day (0.33in/day), or 5.9cm/wk (2.33in/wk). The 0.8cm/day (0.33in/day) rate may be compared with the 25.0cm/hr (10in/wk) permeability listed in Table 10. The larger figure is for uninhibited vertical infiltration into the soil. The smaller figure only about 3.3 percent as large is the limitation imposed by the horizontal hydraulic capacity of the sand aquifer when drained with drains of the size and spacing indicated. The drainage capacity could be much larger, if a closer spacing of drains would be used. However, a larger capacity did not appear to be required, and the increased cost of a larger capacity was thereby avoided.

The perforated plastic drain pipes discharge into solid concrete drain pipes, and these in turn into open ditches. The latter discharge into one of two creeks: Mosquito Creek on the north, and a branch of Black Creek on the south. See Figure 15. The concrete pipes also have small perforated plastic pipes laid alongside, these being terminated at close intervals into connections to a larger concrete pipe, so that the concrete pipe itself would function as a drain following its installation.

About 65 percent of the irrigation area is serviced by the north drainage ditch which has gravity flow into Mosquito Creek. In the case of the south drainage ditch which serves 35 percent, the drain inflow must be lifted to Black Creek by a pumping station; the station is equipped with 322.4kw (30hp) pumps with a capacity of 35.6 TCMD (9.36 MGD). The drain inflow rate for this south ditch is about 11.4 TCMD (3 MGD) during the winter and about twice that during irrigation in the summer. See Figure 15.

There are three areas drained only by drainage wells. One such parcel of about 160 ha (400 a) is located primarily in circles 36, 37, 39 and 40. The reason is that circles 39 and 40 were used as test areas for prototypic irrigation machines during the pre-construction studies, and groundwater from these wells provided a test water supply prior to the arrival of wastewater at the site.

The other two locations drained by wells are along the western aspect of the storage lagoons and along the south side of circles 1 and 2. Here wells were necessary because the depth of the water table, from 7 to 20 m (20-60 ft) made drainage tiles unfeasible. These wells are indicated in Figures 15 and 16.

Each well is equipped with a 7.5 kw (10 hp) pump and a floatation level-control device. The wells discharge into plastic (PVC) polyethylene pipes which convey the pumped water to the drainage ditches.

That area of land not serviced by either drainage tiles or wells is about 200 ha (500 a), and this is drained naturally. It is located along the northern perimeter of the irrigated farmland, and here the depth of the groundwater is more than 7.6 m (25 ft) due to the downward gradient of the water table toward low-lying Mosquito Creek. There are no inhabitants in this area, and the chance of contaminating a water supply is considered remote. See Figure 17.

These elements comprise a system with an overall drainage capacity of 0.8 cm/day which is 5.9 cm/wk. This may be compared to a design maximum rate of application of irrigation water plus precipitation of 9.6 cm/wk (3.8 in/wk). The difference of 3.7 cm/wk (1.5 in/wk) is then the design minimum evapotranspiration during such a period.

Soil Characteristics

As mentioned earlier, that characteristic of soil which is of primary significance to water renovation by sprinkler irrigation is permeability, and permeability together with rate of crop-nutrient uptake (during the growing season) determine the rate at which irrigation wastewater is applied. At the WMS site, the rates of water infiltration into the various soils are: for sandy soils, from 12.5 to 25 cm/hr (5 to 10 in/hr); for loamy soils, from 6.25 to 25 cm/hr (2.5 to 10 in/hr); and for clay soils, from 0.05 to 6.25 cm/hr (0.02 to 2.5 in/hr).

In Table 10 below are listed the major soil types found at the project along with the hydraulic loading characteristics of each, as determined by Bauer Engineering.

Table 10. WMS SOIL TYPES, WATER HOLDING CAPACITIES AND PERMEABILITIES

Type	Water Holding Capacity, cm/m of soil depth		Permeability, cm/hr	
Roscommon	Very low	2-4	Very rapid	25.0
Rubicon	Very low	2-5	Very rapid	12.5-25.0
Au Gres	Very low	2-4	Very rapid	25.0
Granby	Very low	3-10	Very rapid	6.25-25.0
Nester	High	17	Slow	0.05- 6.25

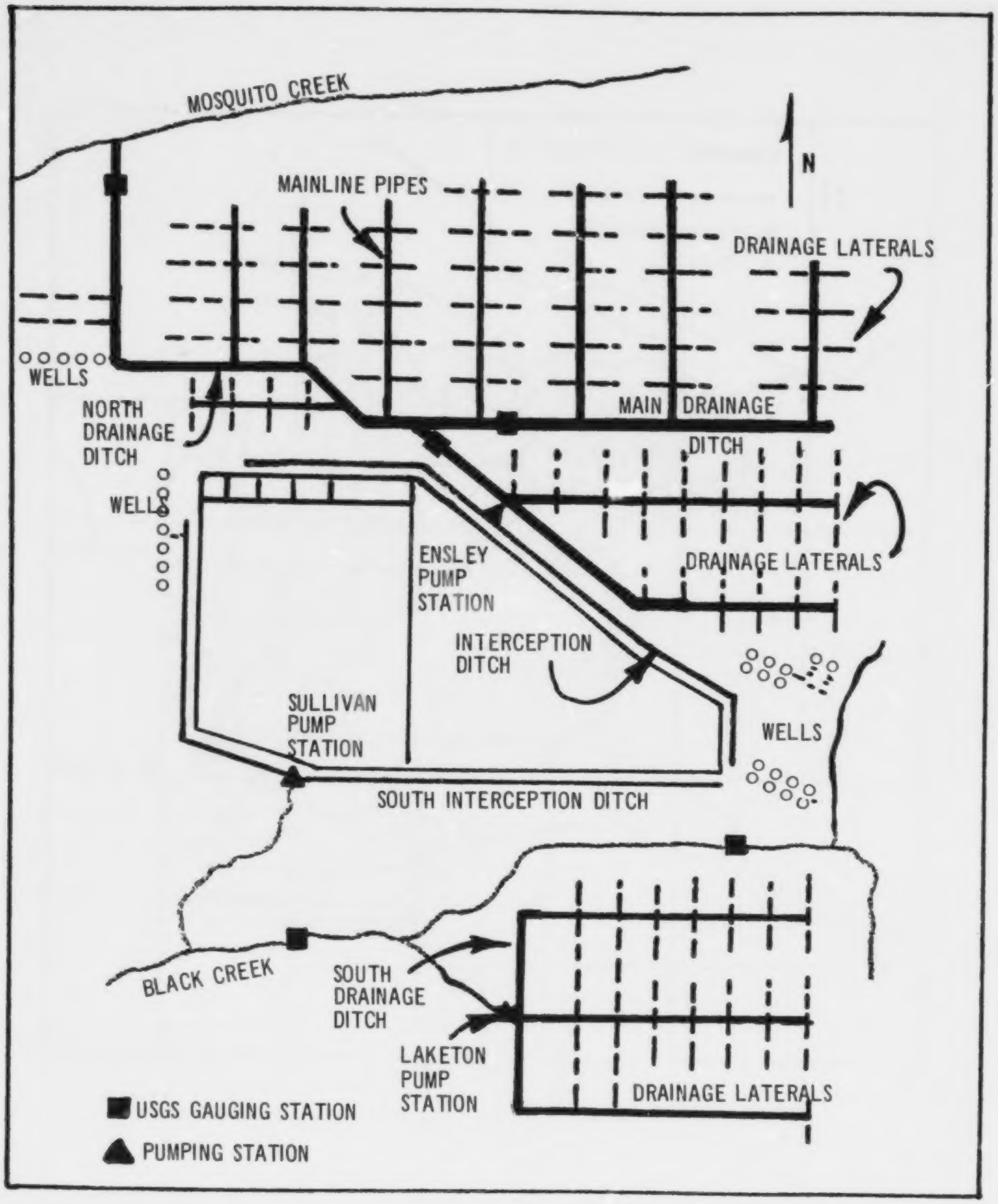


Figure 15. Major components of the WMS drainage system

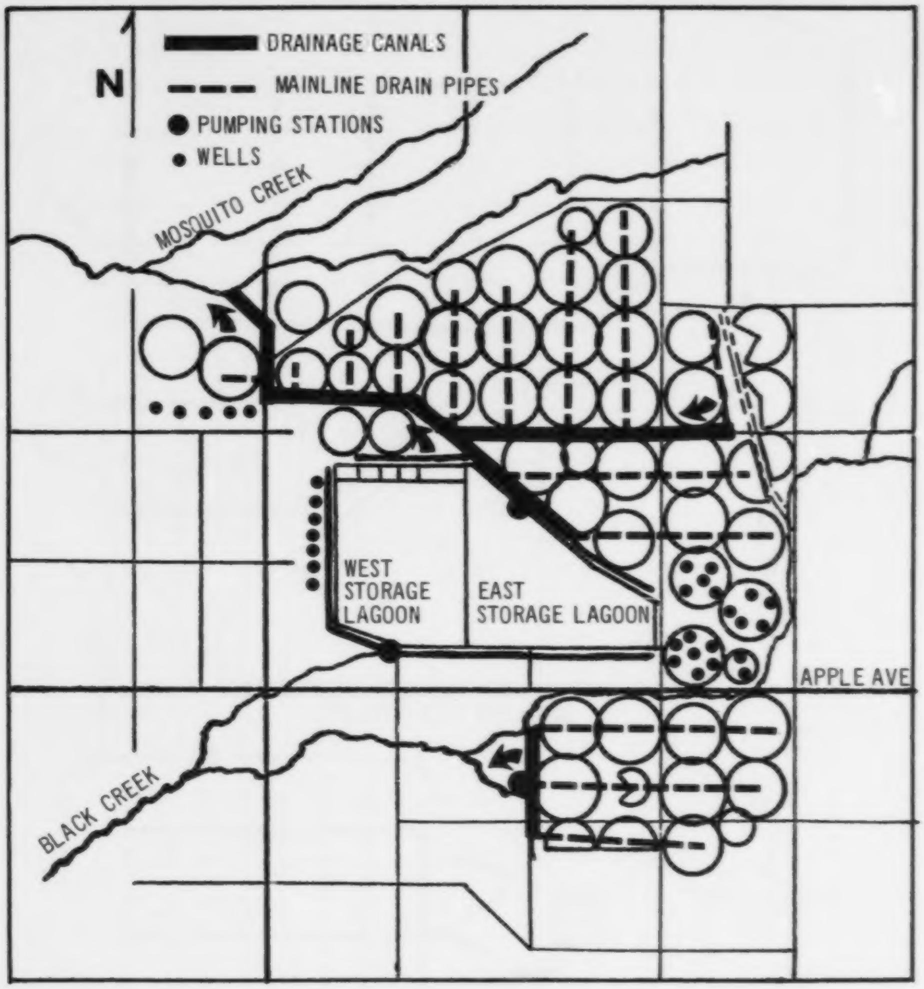


Figure 16. Drainage system in relation to irrigation circles

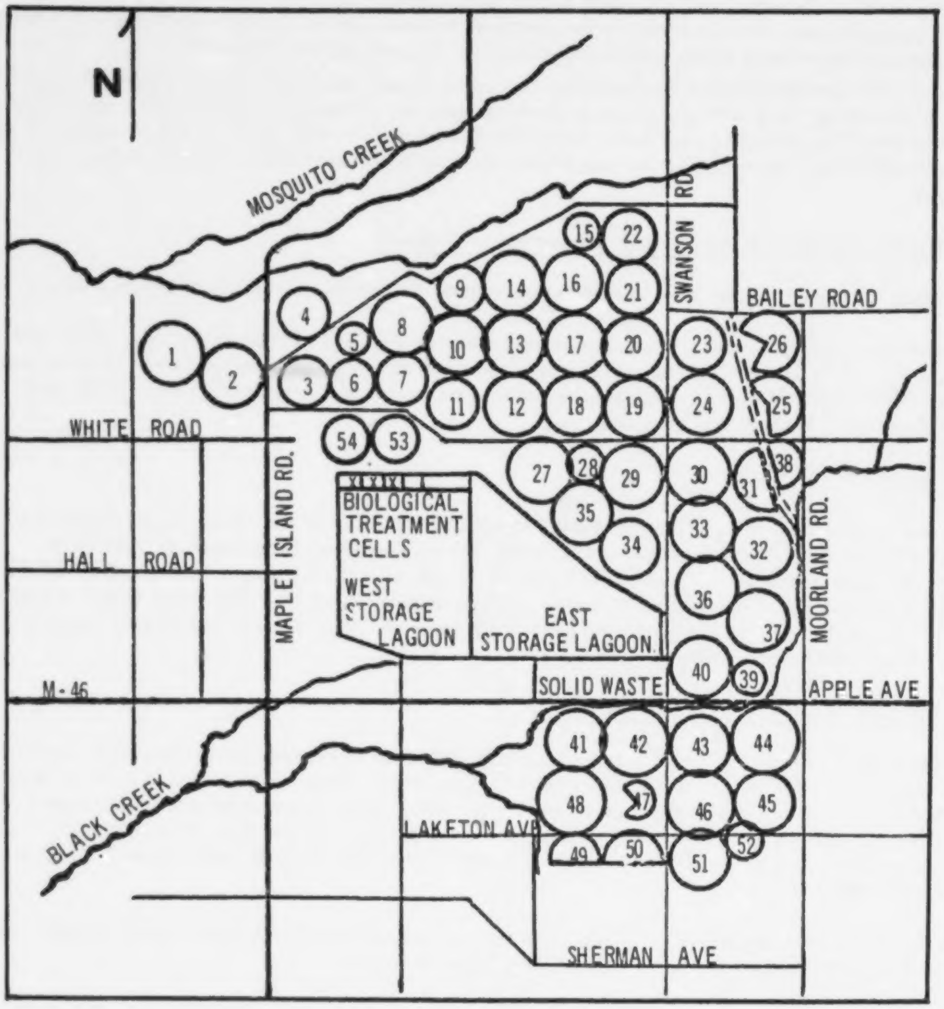


Figure 17. Irrigation circles and treatment aspects in relation to main roads

Rubicon, Roscommon and Au Gres are all poor, sandy soils. Rubicon is the least organic and Au Gres the most organic. Nester is mostly heavy clay, and Granby is loamy sand. Those varieties characterized as "sandy" contain sands which differ greatly in mesh; and each type may vary widely in phosphorus content which is so important to heavy metal complexing in soil. For the distribution of these soil types under irrigation, see the soil map in Figure 18.

Acting on the advice of Bauer Engineering, Muskegon County readvertised the project through 18 smaller contracts, each with its separate prime contractor. This approach in combination with contract revisions aimed at cost reduction yielded total construction bids of $28.5 million. With contract additions, the construction costs were ultimately to rise to $31.5 million before completion.

Construction of the Collection and Transmission Network

Excluding land acquisition, this component comprised 35 percent of the construction costs.

Installation of the force mains and the pumping stations was done between October, 1971, and June, 1973. With extremely minor exceptions, the collection system was on line to receive wastewater in late April, 1973. All pipeline networks were completed between October, 1971, and November, 1972, without major delays.

Excavation

Cost associated with excavations amounted to about 35 percent of the total. In the formation and installation of the aeration and storage lagoons, the amount of soil removed was 2.29 MCM (3 million cubic yards), over an area of 8,645 ha (3,500 a). The digging of the drainage ditches involved over 16 km (10 mi) of excavations. All excavation work was completed within a period of 8 to 12 months; aeration lagoons were ready by January, 1973, storage lagoons by June, 1973, and drainage ditches by February, 1973.

Construction of the Distribution Network

The distribution segment, including irrigation pressure pipelines, electrical lines and irrigation rigs, represented 11 percent of the total construction costs. Sequencing required that the pipelines and underground cables be installed after the completion of the underground drainage system, so full-scale construction of these elements did not begin until September, 1973, and most of the work was not completed until late winter. The pipeline-electrical work lasted from September, 1973, until April, 1974.

Installation of the irrigation rigs spanned the eleven month period of August, 1973, to June, 1974, and was likewise sequenced after the underdrainage system.

Construction of the Underground Drainage System

Underdrainage costs amounted to 9 percent of the total construction costs. The installation of 109 km (68 mi) of plastic drain laterals was accomplished in five months (June-October, 1973) by the use of laser devices mounted on excavating equipment; this new technique lowered manpower requirements, minimized excavation excesses and dramatically lowered costs.

Completion of the concrete mains took one year.

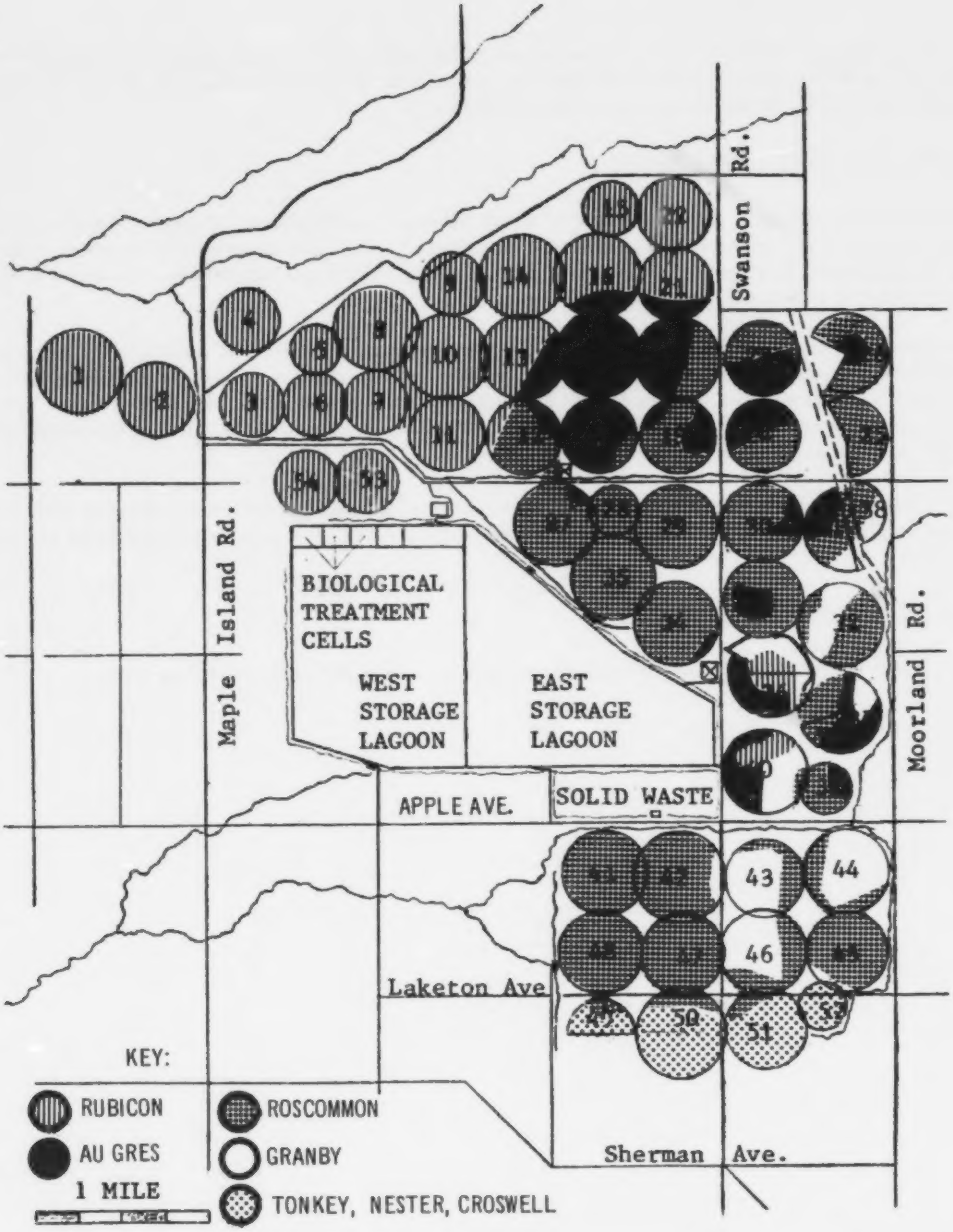


Figure 18. Soil Map of WMS Irrigation Circles

To assay the importance of the laser technique in lowering construction costs, refer to the original bids: of the $50 million total original bid, the cost of installation of underdrainage by conventional means was $12.5 million. Actual cost was $758,000.

Construction: Approach and Timing

Judged by any standard, the time frame in which all major construction components of the project were completed is remarkable: a period of 20 months. That it was completed in so short a time may be attributed to a spirited collective effort on the parts of the contractors, engineers and administrative personnel. Start up was May 8, 1973.

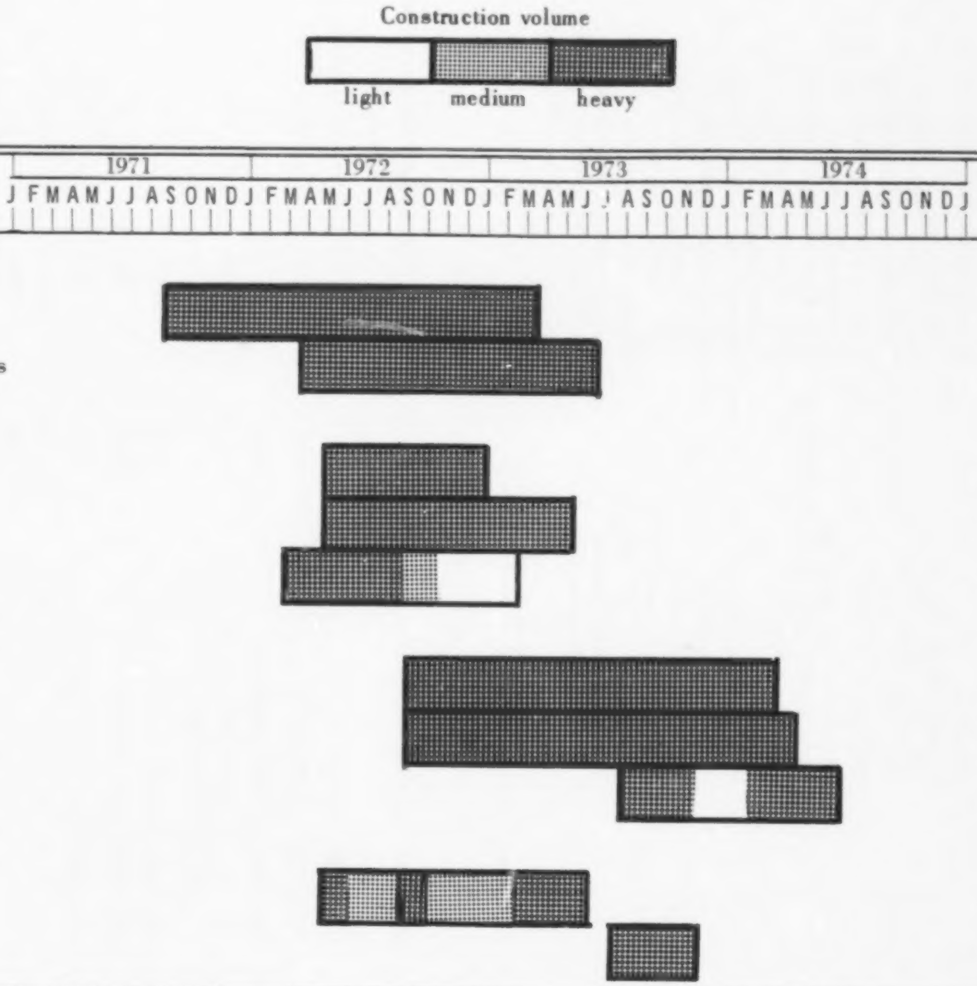
The construction process was not without minor setbacks. In an effort to optimize the construction sequencing, a system was adopted of soliciting bids through one prime contractor, who would in turn have several sub-contractors install individual system components. This centralized approach was eventually rejected, however, when bids for the completed system totalled in the neighborhood of $50 million, in contrast to the engineers' estimate of $26.3 million.

The timetable of start and finish for each major segment of construction is graphically illustrated in Table 11. Immediately following in Table 12 is the listing of contracts, descriptions and contractors.

Land Allocations for Various Uses

For a breakdown of the acreage allocated to various project functions, see Table 13.

Table 11. CONSTRUCTION TIMETABLE



Construction activities	Construction period
Collection:	
Force mains	9/71 to 3/73
Pumping stations	4/72 to 6/73
Treatment:	
Aeration cells	5/72 to 1/73
Storage basins	5/72 to 5/73
Ditches	3/72 to 2/73
Distribution:	
Irrigation pipe	9/72 to 3/74
Electrical	9/72 to 4/74
Spray rigs	8/83 to 6/74
Underdrainage	
Main drains	5/72 to 5/73
Laterals	6/73 to 10/73

Table 12. LIST OF CONTRACTORS

Contract number	Description	Contractors
1	Clearing	Bowen-Milas, Incorporated
2	Plastic Drain Pipes	Agri-Drainage
3	Concrete Drain Pipes	Chris Nelson, Incorporated
4	Culverts	Brown Brothers, Incorporated
5	Ditches	Maclean Construction Company
6	Irrigation Pressure Pipe	Eisenhour Construction Company
7	Administration & Chlorine Buildings	J.C. Construction Company
8	Electrical System	M.J. Electric Company
9	Wells	Layne Northern Company
10	165 cm Force Main	Oberer Construction Company
11	90 cm Force Main	Bowen-Milas, Incorporated
12	90 cm Force Main	T.A. Forsberg, Incorporated
13	75-90-105 cm Force Main	G.A. Odien Company
15	Pump Station "C" (Main)	Muskegon Construction Company
16	Package Pump Station	Brown Brothers, Incorporated
17	Irrigation Pump Station	Muskegon Construction Company
18	Lagoons	Holloway Sand & Gravel Company
22	Irrigation Spray Rigs	Lockwood Corporation

Table 13. ACREAGE ALLOCATIONS AT WMS

Purpose	Allocation		Percent of total
	Acres	Hectares	
Irrigated with wastewater	5350	2167	49
Wastewater storage lagoons	1700	689	16
Solid waste landfill & municipal & industrial development	1500	608	14
Ditches & roads	1000	405	9
Dry land farmed borders	1000	405	9
Aeration, settling, outlet lagoons, chlorination & other buildings	300	122	3
Total	10850	4395	100

SECTION 5

IRRIGATION EQUIPMENT OPTIMIZATION PROGRAM

Two types of center-pivot irrigation rigs similar to those used for large-scale farm irrigation in the western states were tested at the project site for structural and hydraulic performance under the anticipated operating conditions of wastewater application. All pertinent operating characteristics and maintenance requirements were recorded during the 1972-1973 testing period, which was completed in December, 1973.

The two test rigs, one manufactured by Enresco, Colorado Springs, Colorado, and one by Lockwood of Gering, Nebraska, were erected in circles 39 and 40 in 1972 while other aspects of the WMS were under construction. See Figure 19. The rigs were similar: each was originally about 400 meters long and was comprised of 35 meter sections. The Enresco rig was shortened from 400 to 200 m to fit circle 39.

Each 35 meter section was suspended about four meters above the ground by an A-frame tower mounted on tires with the wheels driven by electric motors. Beneath each rig section about two to three meters above the ground, a spraybar about six cm in diameter was suspended. Nozzles on the spraybar were from one to two meters apart.

The spraybar connection to the mainline pipe was either by rigid pipe or flexible hose.

The pivot to which the rig is attached was a steel-framed tetrahedron through which the mainline rig pipe was coupled to the water source. Near the pivot but mounted on the rig was an electric control center through which rotation rate was regulated.

Table 14 contrasts the physical and operational characteristics of the two rigs.

Wastewater was not yet available for the testing program, so groundwater was pumped from wells to the rigs. The water was applied to a variety of crops in the two circles; see Figure 19 for the cropping map.

The operations timetable for the overall project required that the specifications for irrigation rig purchases be delineated about halfway through this testing program. Nonetheless, the testing program was completed because it was felt that much valuable information was obtained from the completed test program which would be beneficial to future rig operation.

The tests performed on the rigs are listed in Table 15, showing which rigs were involved in the eleven tests.

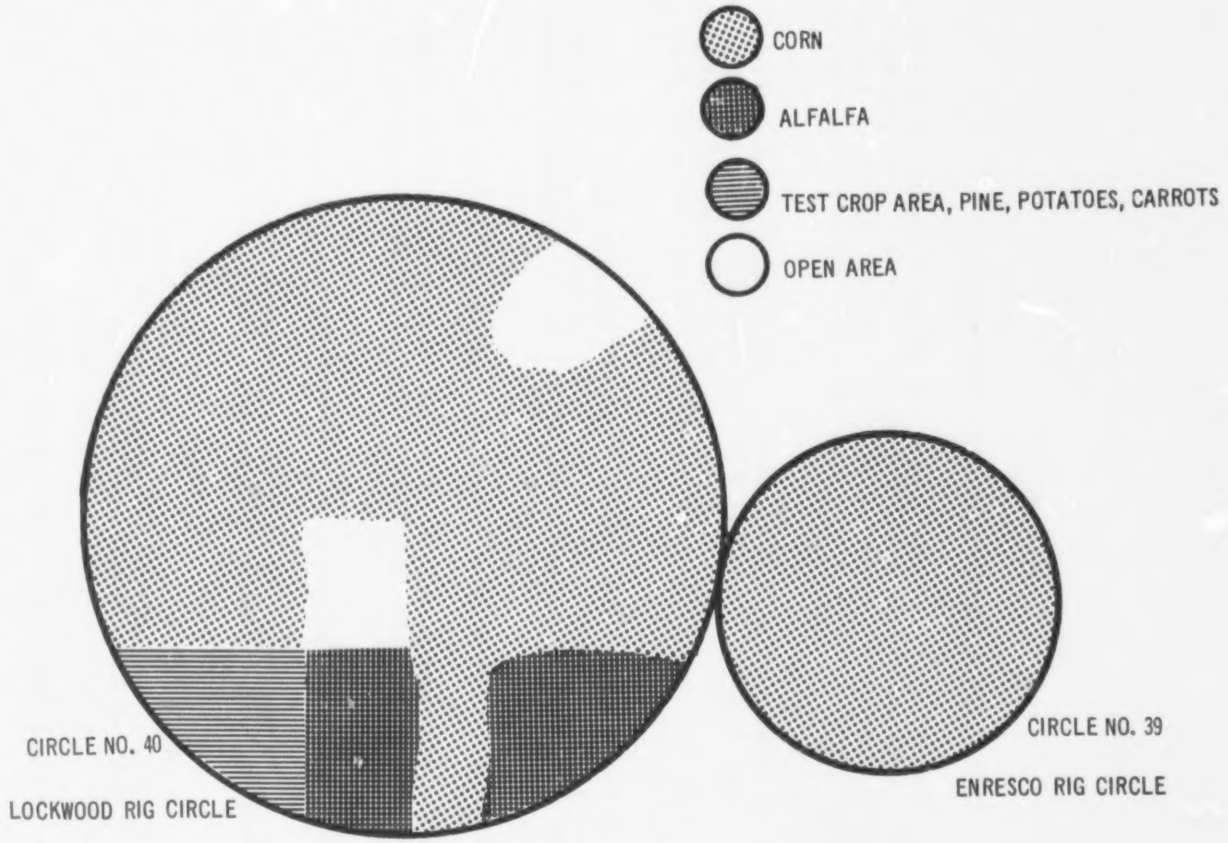


Figure 19. Test location circles 39 and 40 cover crop layout

Table 14. PHYSICAL AND OPERATIONAL CHARACTERISTICS FOR EACH IRRIGATION MACHINE TESTED

Rig characteristics	Enresco	Lockwood
PHYSICAL		
Length, meters		
entire rig	400[a]	400
section	9 at 29 & 3 at 44	39
end section	7	10
number of sections	12	10
Mainline pipe		
diameter, cm	16 & 21	16 & 20
material	Black iron	Galvanized steel
structural suspension	Truss	Cable
Spray bar		
diameter, cm	8	4, 5, & 8
material	Black iron	P.V.C.
distance from ground, m	3	3
Nozzles		
type	Floodjet	Floodjet
orifice diameter, mm		
minimum	44	23
maximum	115	71
Tower		
wheel type	Rubber & steel	Rubber & steel
wheel diameter, cm	120	120
motor type	480 volt, 3 ϕ	480 volt, 3 ϕ
motor horsepower	1	1
Area irrigated, hectares	12.5	50
OPERATIONAL:		
Mechanical		
wheel revolution, rpm	1-2	0.8
rig rotation at 100 percent, hr/rev	12	18.5
Hydraulic		
discharge rate, m^3/hr	50	50
application at 100 percent, cm/rev	0.70	1
spray bar pressure, g/cm^2	210	700-1500

[a] Modified to 200 m for circle 39

Table 15. TESTS PERFORMED ON THE ENRESCO AND LOCKWOOD RIGS

Test No.	Description	Rig Tested	
		Enresco	Lockwood
1	Coefficient of uniformity determination	X	X
2	Effects of water volume on plants		X
3	Soil infiltration		X
4	Efficiency of maximum application rate		X
5	Soil moisture		X
6	Surface runoff		X
7	Wind drift	X	X
8	Winter operation	X	X
9	Rig shutdown	X	
10	Rig stability	X	X
11	Wheel rut	X	

TEST 1, COEFFICIENT OF UNIFORMITY

The purpose of this test was to evaluate the uniformity of water application by the rigs. A common approach is to place sampling containers in an organized pattern within the application range of the rig, and, after a period of operation, the water volumes in the containers are measured. The data were interpreted statistically using Christiansen's formula[6] for coefficient of uniformity (CU) expressed as percent:

$$CU = 100[1 - (x/MN)]$$

Where: M = average volume, all observations
N = number of observations
x = sum of deviations from M

Thus an application which is absolutely uniform has a CU of 100 percent. A more practical expectation, however, is a CU of 85 percent; this allows for a level of uniformity which is satisfactory for most crops, and the technological demands of the equipment remain in a range which permits manufacture at a reasonable cost.

Figures 20 and 21 illustrate the placement of the sampling containers.

The volume of water in each cup was measured immediately after the pass of the irrigation rig. In the case of the Lockwood rig which was 400 meters long, over 400 samples were measured, requiring about two hours to record a single pass. To equalize possible losses due to evaporation,

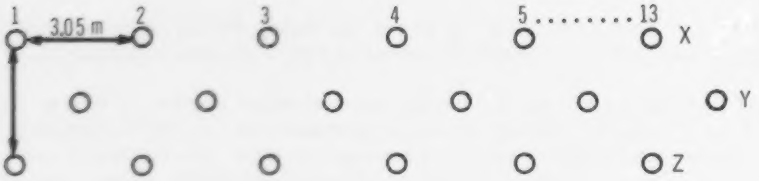


Figure 20. Cup sampling pattern between towers for coefficient of uniformity test

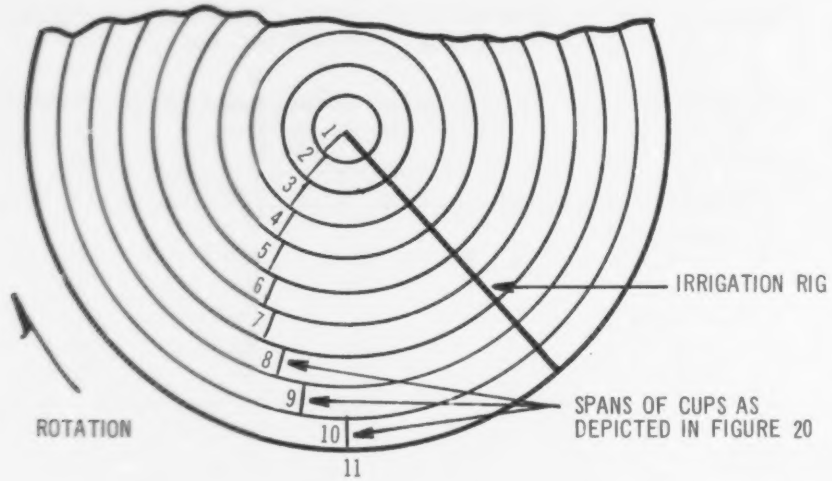


Figure 21. Arrangement of staggered cups in circles 39 and 40 for coefficient of uniformity test

the cup patterns were staggered as in Figure 20. So as data from one span were being recorded, spraying in the adjacent span was in progress.

Two such tests were performed on the Lockwood rig, during the day and at night both with zero wind velocity. The CU results were 81.3 percent and 81.4 percent, respectively.

In the case of the Enresco rig, the first test was performed at sunrise, at or near zero wind velocity, and the CU was 67 percent. It was thought that this low value might have been due in part to the difference in operating pressures between the rigs. The Lockwood sprayed at about 700 g/cm^2 and the Enresco at about 210 g/cm^2. For the second test of the Enresco rig, operation pressure was elevated to about 350 g/cm^2, and the resulting CU increased to 71.6 percent. This CU value was still below the 85 percent desired.

Table 16 lists the spraybar pressures and corresponding coefficient of uniformity. Individual test data may be found in Tables 1 and 2 in Appendix A.

Table 16. COEFFICIENT OF UNIFORMITY AND SPRAYBAR PRESSURE IN LOCKWOOD AND ENRESCO RIGS

Prototype	Spraybar pressure, g/cm^2 Design	Spraybar pressure, g/cm^2 Observed	Coefficient of uniformity, percent
Enresco			
test one	700	210	67.0
test two	700	350	71.6
Lockwood			
test one	700	700	81.3
test two	700	700	81.4

Conclusions

Although neither rig achieved the CU specification of 85 percent, the Lockwood performance was superior to that of the Enresco.

Within limits, a more uniform spray may be achieved by increasing spraybar pressure.

Recommendations

On a provisional basis, the Lockwood rig should be accepted. Nozzle spacing should be redesigned to improve uniformity of spray.

The spraybar of the Enresco rig should be completely redesigned with special attention devoted to nozzle size and spacing. Spraybar pressures should be re-evaluated with the new design to achieve a satisfactory CU. It was recommended that on the basis of the CU test the Enresco rig not be accepted.

TEST 2, EFFECTS OF AMOUNTS OF IRRIGATION WATER ON VEGETATIVE COVER

The purpose of this test was to evaluate the extent of damage done to crops by the intensity of water spray from the rig.

To maximize the impact of water on the plants and at the same time greatly increase the rate of application, the rate of revolution of the rig was set at five percent. In Table 17, rotation rates and application rates are contrasted for five and 100 percent rotation rates for the Lockwood rig. See Appendix A, Table 3.

Table 17. LOCKWOOD RIG ROTATION RATES AND WATER APPLICATION RATES

		Water application rate	
Timer setting, percent	Rotation rate,[a] hours	Average,[b] cm/rev	Instantaneous,[c] cm/hr
100	18.5	1.1	16.0
5	370	22.0	320

[a] Time required for one complete revolution

[b] Total amount of water sprayed divided by area sprayed in one revolution

[c] Amount of water in a single sample divided by the sample collection time

The plants on which the test was performed were seedling corn about ten cm high, a stage at which the plants are regarded as very vulnerable to damage.

No damage to the crop was observed.

Conclusions

High intensity spray within the range tested does not damage corn seedlings.

Rig rotation rate may be lowered to five percent.

Recommendations

The speed of rig rotation should be dictated by factors other than intensity of spray.

TEST 3, SOIL INFILTRATION

The purpose of this test was to determine the rate of water infiltration into the soil of circle 40 as related to rate of water application. Surface sealing was to be evaluated, also.

Infiltration rates were measured in the northwest, northeast and southeast quadrants of circle 40 before, during and after the irrigation season.[7] An intake cylinder 30 cm in diameter was driven into the ground to a depth of about ten cm and filled with water, the initial level of water and time were recorded. Subsequent levels and times were recorded as the water seeped into the soil.

That time at which the infiltration rate became minimum was correlated with the delivery rates of the irrigation rigs. The rig while in operation was irrigating bands or strips of soil three meters wide, and the time during which the strip was receiving water was determined by the rotation rate of the rig, which was, in turn, controlled by the percentage timer. Rates of application and times of application are tabulated with timer settings in Table 18.

Table 18. DURATION AND RATE OF APPLICATION WITH CORRESPONDING TIMER SETTINGS FOR IRRIGATION OF THREE-METER STRIP

	Timer setting, percent									
Parameter	100	90	80	70	60	50	40	30	20	10
Duration time, minutes	4.00	4.40	5.00	5.70	6.70	8.00	10.0	13.3	20.0	40.0
Application rate, cm/rev	1.00	1.10	1.30	1.40	1.70	2.00	2.50	3.30	5.00	10.0

For each quadrant, the times at which the infiltration rates became constant were averaged and are presented in Table 19. The wide range in infiltration rates reflected soil types within the circles: Q-1 was sandy loam; Q-2 was highly permeable sand; and Q-4 was heavy loam.

Table 19. AVERAGE TIMES WHEN BASIC INTAKE RATE BECAME CONSTANT

	Quadrant number		
Parameter	1[a]	2[b]	4[c]
Time, minutes	22	25	20
Intake rate, cm/hr	17	28	9

[a] Sandy loam
[b] Sand
[c] Heavy loam

Comparison of Tables 18 and 19 allows selection of rig rotation rate by use of soil infiltration rates. Thus, a timer setting of 20 percent with an application rate of five cm/rev should provide an optimum amount of water for circle 40, with no ponding and no significant runoff.

Conclusions

The rates of infiltration within the test circle were well within the delivery limits of the irrigation rigs. Operation of the rigs at rotation rates near 20 percent was indicated for soil types similar to those in circle 40.

Recommendations

Rotation rates corresponding to timer settings near 20 percent were recommended. If soil type presents ponding or runoff, timer settings should be increased until the problem is corrected.

The slower rotation rates should provide more economical operation, for power consumption is directly proportional to rate of rotation. It was expected, also, that maintenance-repair incidence would be reduced with reduced rotation rates.

TEST 4, EFFICIENCY OF MAXIMUM RATE OF WATER APPLICATION

The purpose of this test was to compare theoretical and actual water application rates by the irrigation rigs under varied field conditions.

The theoretical application rates[8] were calculated with the use of an application constant (cA) in cm/hr which was determined from the equation:

$$cA = Q/100A$$

Where: cA = application constant in cm/hr
Q = flow rate in m^3/hr
A = area irrigated in hectares
100 = unit constant

Because the rig length is fixed and the flow rate is assumed to be constant, the cA for a given rig is always constant. For the two rigs tested, the length of rig, flow rate, area irrigated and application constant are listed in Table 20.

Table 20. COMPARISON OF THEORETICAL APPLICATION CONSTANT FOR LOCKWOOD AND ENRESCO RIGS

Prototype	Flow rate, m^3/hr	Rig radius, m	Area irrigated, ha	Application constant, cm/hr
Enresco	82	205	13.2	0.062
Lockwood	306	396	49.3	0.062

In continuous operation – at 100 percent time setting – the times required to complete one revolution for the two test rigs were 6.75 hours for the Enresco and 18.5 hours for the Lockwood. Using the application constants and times per revolution, the theoretical application rates (in cm/rev) were calculated for the various timer settings for each rig. These are tabulated in Table 21. In Figure 22, the theoretical rates and the observed application rates are plotted. The observed rates were determined by the same collection cup technique used for the test for coefficient of uniformity. (Observation data are listed in Tables 3 and 4 in Appendix A.)

Table 21. REVOLUTION TIMES AND THEORETICAL APPLICATION RATES WITH CORRESPONDING TIMER SETTINGS FOR PROTOTYPIC IRRIGATION RIGS

Timer setting, percent	Time per revolution, hours		Application rate, cm/rev	
	Enresco	Lockwood	Enresco	Lockwood
100	6.75	18.5	0.43	1.14
90	7.50	20.6	0.48	1.27
80	8.44	23.1	0.53	1.42
70	9.64	26.4	0.61	1.63
60	11.3	30.8	0.71	1.91
50	13.5	37.0	0.84	2.29
40	16.9	46.3	1.07	2.87
30	22.5	61.7	1.42	3.81
20	33.8	92.5	2.11	5.74
10	67.5	185	4.24	11.5

Conclusions

It is possible to deliver with the prototypic irrigation rigs rates of water application which correspond closely with the theoretical application rates. This high level of predictability should afford maximum control of application of wastewater in accordance with soil infiltration capacities and crop needs.

Recommendations

Rigs should be operated at that rate of rotation which best satisfies soil-crop tolerances and needs.

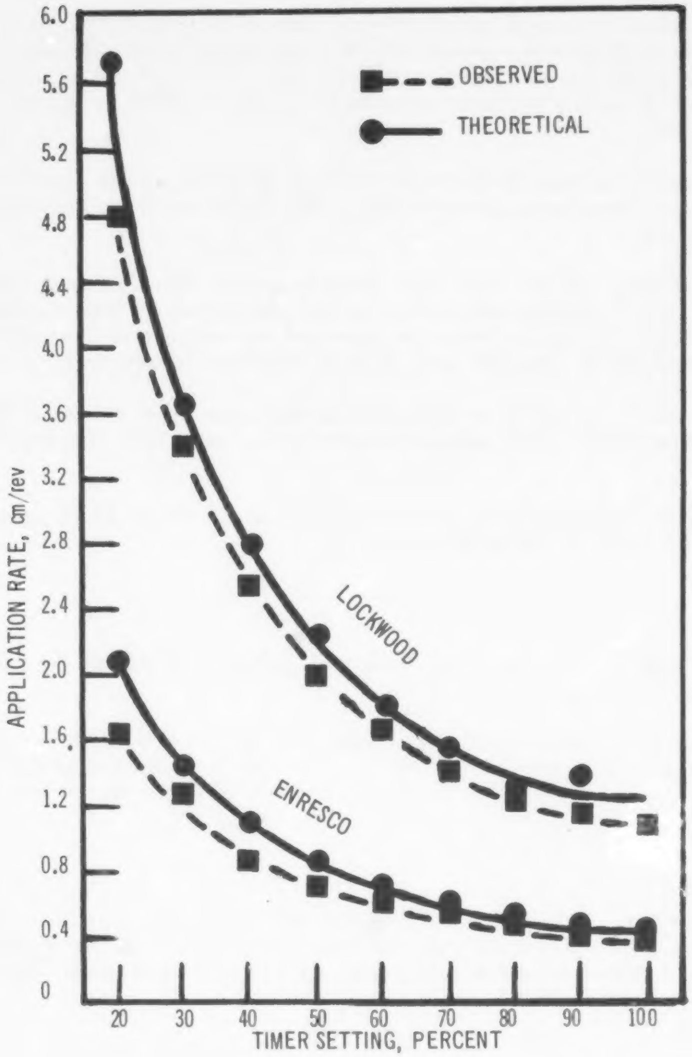


Figure 22. Comparison of theoretical and observed application rates for the Enresco and Lockwood irrigation machines

TEST 5, SOIL MOISTURE TEST

The purpose of this test was to determine the behavior of water in soil when sprayed from rigs.

Two soil types in circle 40 were used, a light brown medium sand about 120 cm deep and a black sandy loam to a depth of 25 cm with a subsoil of light brown medium sand. The sand was left barren, and the black sandy loam was planted with field corn. Soil moisture was measured at 30, 60 and 120 cm depths. Measurements were made along the same arc of the Lockwood rig to insure equal water application.

Soil cells* were buried at the three depths with wires from the cells extending to a terminal box at the surface. Readings were taken as percent of dry weight of soil with a Soiltest moisture meter connected to the terminal.

Baseline readings on either soil type were taken before irrigation. The rig then applied water at a rate of 7.5 cm/rev, the 7.5 cm representing the maximum design rate for WMS. Immediately after the rig passed over the test sites, readings were taken and repeated at intervals until stable moisture content was observed. A single pass of the rig was used for each test.

Barren sand showed great permeability with the most moisture retained at a depth of 60 cm. Moisture was detected at the bottom of the normal root zone almost immediately after irrigation. See Figure 23.

The cropped sandy loam retained moisture in the upper layers so well that added moisture was not detected at the 120 cm level, as indicated in Figure 24.

Conclusions

High rates of water application on sandy soil caused rapid percolation through the top 30 cm and moderate retention at 60 and 120 cm.

The sandy loam tests were done after harvesting field corn, and it was possible that the plant roots contributed to the soil water-retaining ability. The sandy loam demonstrated a large capacity for water retention in the top layers of the soil, and applied water was not detected at 120 cm depth after 144 hours.

Recommendations

Irrigation rigs on very sandy soil should be operated at the fastest rates of rotation. With frequent applications of low rates of application, a more uniform moisture profile may be achieved. More effective wastewater treatment should be achieved by the enhanced opportunities for soil-nutrient reaction.

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*Soiltest, Inc., Model MC-300A, Evanston, Illinois

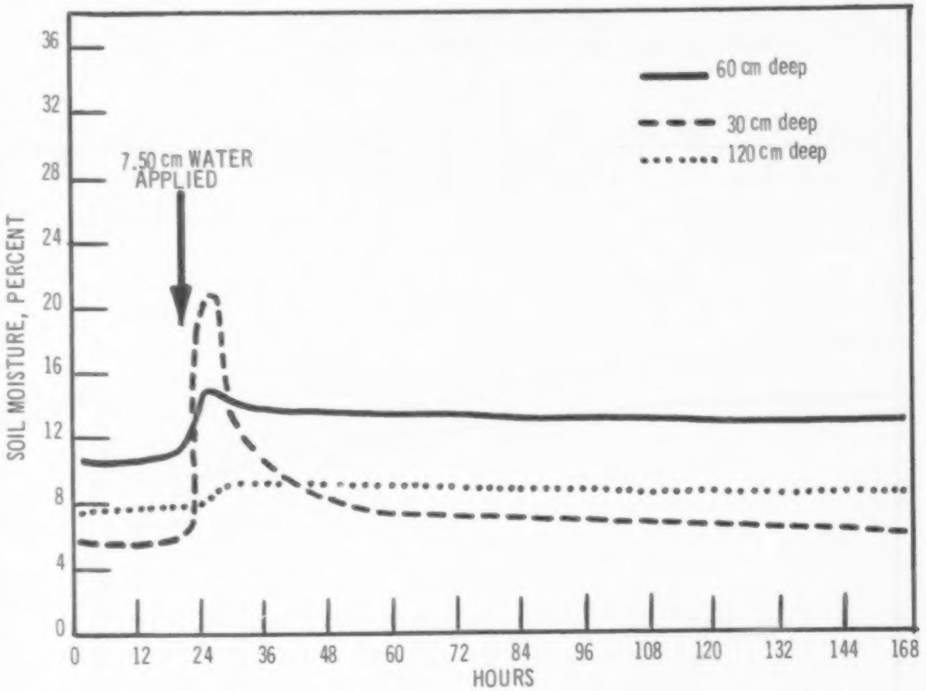


Figure 23. Soil moisture in barren sand at three depths before, during, and after irrigation

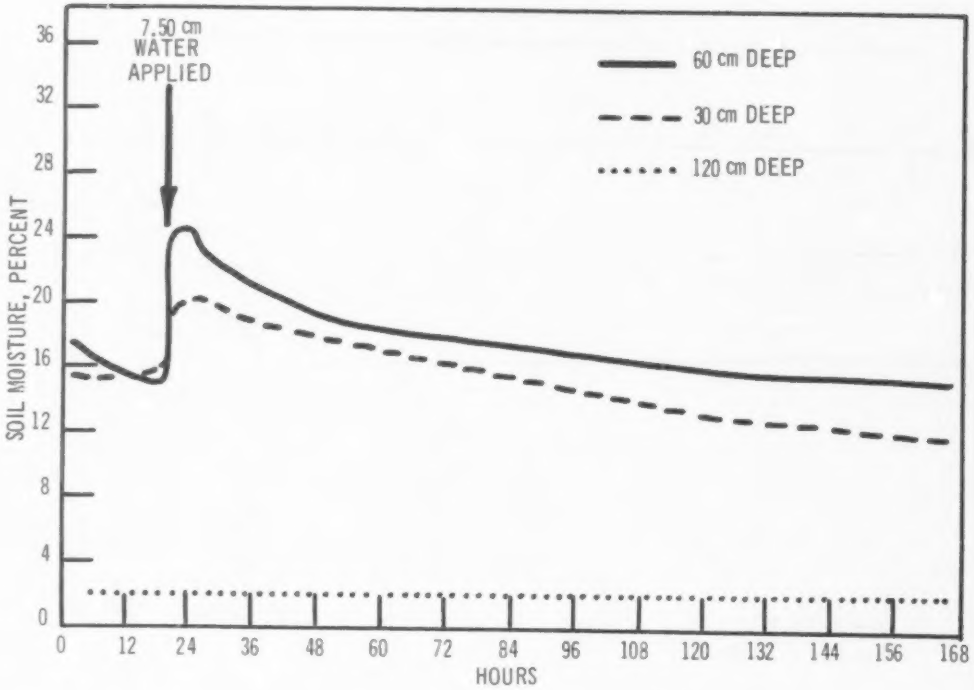


Figure 24. Soil moisture in cropped sandy loam at three depths before, during, and after irrigation

Sandy loam irrigation should be done at slower rates of rotation and higher application rates. Such corn-cropped soil has greater water-retention capacity, and slower rig operation costs less.

TEST 6, SURFACE RUNOFF TEST

The purpose of this test was to determine the slowest rotation rate at which a rig may be operated without causing surface runoff. The fewer revolutions required per season to apply wastewater, the less is the operational cost. That optimum rotation rate is the one which satisfactorily irrigates the crop at minimum expense.

The procedure was to try various rotation rates on the Lockwood rig until runoff and sealing were achieved. The setting at the start was 50 percent, or half of the rig's maximum speed. If runoff and sealing were not observed at this speed, the rig would be slowed until the conditions were created. If they did occur at this rotation rate the speed would be increased until the conditions no longer appeared. Thus, it would be possible to ascertain a rotation rate five percent greater than the runoff threshold, an optimum rate.

It should be noted that this test was regarded as a pilot experiment with much subjective evaluation. Rigorous data were not recorded.

The soil during the test was extraordinarily dry, and surface runoff was observed at even the fastest rotation rates, although there was no evidence of surface sealing. It was found that if the soil was maintained in a slightly moist state, it was able to receive large quantities of applied water without runoff.

Conclusions

Based upon the criterion of surface runoff, the optimum rotation rate of the rig is the maximum speed.

Recommendations

Soil moisture content should be influential in determining rig rotation rate. At minimum, rigs should be operated at a rate consistent with keeping the soil surface moist.

TEST 7, WIND DRIFT

The purpose of this test was to determine the sizes of water droplets from the spraybars as a function of wind velocity. Testing was done beyond the irrigation circle at a distance of 60 meters, the minimum width of the buffer zone along the project boundaries. Four tests were performed on each rig.

Wind drift samples were collected on slides coated with magnesium oxide-silicone. Slides were prepared by dipping in two percent collodion in amyl acetate, followed by suspending them above burning magnesium ribbon, providing a coating of magnesium oxide.

Slides were placed downwind from the irrigation rig, and droplets coming in contact with the slide formed stains which were quantified under a microscope. The collodion prevented adhesion of water on the glass and allowed the stain to more accurately depict the droplet size. Control slides were placed upwind from the spraying rig but were otherwise identically treated.

Immediately after each test, the control slides were examined, and, if free of water droplets, the test was regarded as acceptable. Tests in which control slides showed water droplets were repeated; usually such water was from a source other than the irrigation rig, usually atmospheric precipitation. Control slides were exposed to the atmosphere for a period of about 90 minutes prior to and following the test slides.

Weather conditions, including wind speed, wind direction, temperature, relative hunidity and precipitation, were continuously monitored during testing. Equipment for weather monitoring was in a field research trailer outside the south section of circle 40. Wind speed and direction were recorded from a 12 meter tower. Other parameters were measured between one and two meters above ground.

The stains were counted and sized under a microscope by making several traverses across the slide with care to avoid covering the same area twice. Stains were sized by an eyepiece grid and were recorded according to micron size range. Between 100 and 200 drops were counted per slide.

Slides were exposed for varying times. At two minutes, most were nearly stain-free, and at 64 minutes, the slides were densely stained. A total of 100 to 200 droplets is generally accepted as a valid sample for determining average droplet size.[9] The arithemetic mean diameter, or average diameter (D_{avg}), is an expression derived from the number of each group and is represented by the expression:

$$D_{avg} = \Sigma nd / \Sigma n$$

Where: Σnd = sum of the products of multiplying number of droplets in each size by its size

Σn = total number of droplets

The droplet spectrum was reported as the percent of the total number of droplets in the various size ranges and covering the entire size range encountered.

Results

In Figure 25 the results of wind drift tests for two wind velocities are plotted from data in Table 5, Appendix A. The largest number of droplets was of a diameter of about 77μ and was detected at wind speeds of about 15 to 25 kilometers per hour. At higher wind speeds of 30 to 45 kmph, the dominant aerosol diameter was about 92μ. The shift in size as wind velocity increased was thought to be due to a cohesion of droplets at higher speeds, but even within the complete range of wind speeds, the total variation of droplet size did not exceed 15μ.

In Table 22 the droplet diameters are listed for the "high" and "low" wind speeds as they were found at distances from the irrigation rig from 30 to 240 meters. As the distance from the circle increased, droplet size decreased, regardless of wind speed.

Similar findings have been found by other workers.[10]

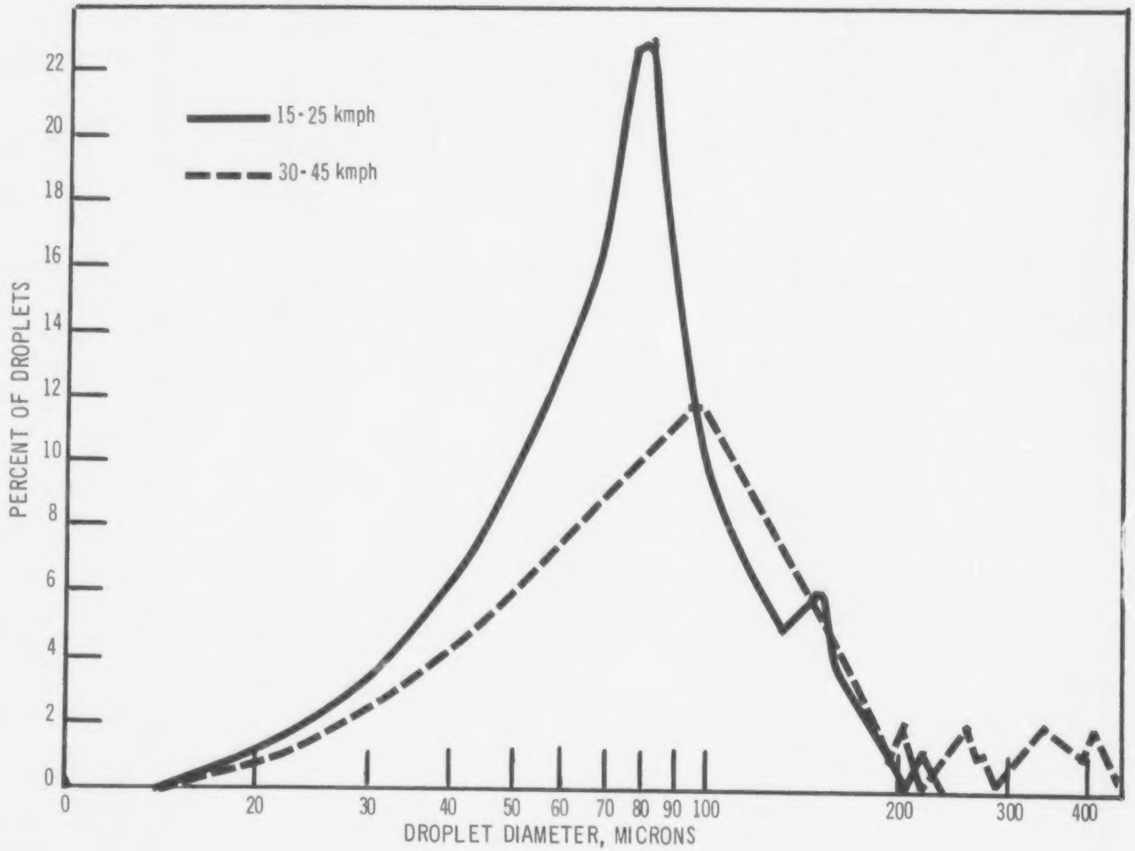


Figure 25. Droplet distribtuion by size at 60 meters at two wind velocities

Table 22. AVERAGE DROPLET SIZE AT VARYING DISTANCES FROM THE RIG AND AT TWO WIND SPEEDS

Distance from rig, m	Droplet size, μ at wind speeds, km/hr 15 to 25 km/hr	 30 to 45 km/hr
30		94
60	72	86
90	58	86
240	26	26

Table 23 lists number and size distribution of droplets at the 240 meter distance. Sizes ranged from one to 54μ on a total number of 22, whereas at 60 meters at the wind speed, the droplet number was 276 with a size range from one to 216μ. Test durations were the same, but at longer distances, fewer drops were found. See Table 5 in Appendix A.

Table 23. DROPLET SPECTRUM AT 240 METERS AND IN 15 TO 25 km/hr WIND

Range in droplet diameter, μ	Number of droplets	Number × diameter	Percent of total
1-13	4	52	9
13-27	16	432	75
27-40	1	40	7
40-54	1	54	9
54-67	0	0	0
Total	22	578	100

Conclusions

Generally, there is an inverse correlation between distance from the rig and aerosol size distribution. At the shorter distances, the number of droplets is greater, and the droplet size is larger. At the longer distances, the number of droplets is small, and the size is smaller.

Recommendations

Spray irrigation should be operated at wind speeds up to 25 kmph at distance no less than 60 meters from the site boundaries.

It was recommended that spraybars be adjustable for height in order to facilitate spraying very close to the ground at times such as before planting and after harvest. During the growing season, the spraybars should be raised to accommodate plant growth.

TEST 8, WINTER OPERATION

It was the purpose of this test to evaluate rig performance under conditions of winter weather. It was anticipated that winter conditions would exist during the earliest and latest weeks of the irrigation season. Of particular interest was ice formation in three areas: within the machines, on the machines and on the surface of the ground.

Winter operation resulted in the following:

(a) Ice formation on chain links caused chain dislocation which disabled the drive transmission and resulted in rig shutdown.

(b) Irrigation spray water accumulated in the vertical motor housings on the chain drive systems. Freezing produced excessive torque on the shaft which lead to motor overheating and rig shutdown.

(c) Although the rigs are equipped with automatic valves for water drainage, after a period of spraying there was not complete drainage. Water accumulated in a short section of the mainline pipe near the end of the rig and also in a few low points along the PVC spraybar. When freezing of this accumulated water took place, both the galvanized mainline and PVC pipes cracked due to the ice pressure.

(d) Operation of the rig in heavy wet snow resulted in snow sticking to the steel spoke wheels and cleats to a thickness of 25 cm.

(e) Operation with frozen ground surface produced runoff in high areas and ponding in depressions.

(f) During April, 1973, rigs were operated in a blizzard at $0^\circ C$ and with winds to 80 kmph. Water sprayed and froze on all parts of the rig. Ice on the alignment mechanism caused malfunction of the primary mechanism and the automatic safety shutdown mechanism. The rigs became severely misaligned, and only manual shutdown by personnel prevented structural damage. The rigs were re-aligned when weather permitted.

Conclusions and recommendations

Rig opeation should be discontinued under winter weather conditions.

All mechanical equipment should be properly sealed or drained to obviate damage due to ice formation.

All piping should be valved for automatic water drainage, thus preventing cracking.

TEST 9, RIG SHUTDOWN TEST

The purpose of this test was to evaluate the effectiveness of the rig anti-collision mechanism.

To reduce the area of unirrigated land implied by placement of circles which "touch" tangentially, the irrigation circles were designed to overlap.

Rigs were equipped with anti-collision devices which function when rigs of adjacent circles rotate in opposite directions. The device consisted of a feeler and a sensor. In the event of a potential collision when a leading rig was nearly overtaken by a trailing rig, the feeler of the leading rig contacted the sensor of the trailing rig. The sensor of the trailing rig signalled the electrical control center to shut down. The other rig advanced from the contact area. The trailing rig automatically started again at its normal rate. See Figure 26.

Conclusions and Recommendations

The anti-collision device performed well and indicates that overlapping irrigation rigs is sound design for efficient land use. It was recommended that such design and such devices be employed at the WMS.

TEST 10, RIG STABILITY

The purpose of this test was to determine for purpose of design the extent of stress limits on the rigs under conditions of uneven terrain.

Because circle 40 was smooth, it was necessary to create rough terrain. A ravine one meter deep and a mound 1.5 meters high were constructed in the paths of two adjacent rig towers. Ascending and descending slopes were graded at 30 percent. In operating the rig over the mound and through the ravine, the characteristics to be evaluated were: ease of passability, cause of shutdown, misalignment or other damage. If the rig failed to negotiate the obstacles, slopes would be reduced until passage without failure was reproducible.

Conclusions and Recommendations

The rigs performed well and were structurally adequate for continuous operations over severely rough terrain.

It was recommended that for future purchases of rigs for the Muskegon project, structural specifications be equal to or greater than those used in this test.

TEST 11, WHEEL RUT

The purpose of this test was to determine the extent to which wheel rut formation would affect rig operations.

The Enresco and Lockwood rigs were equipped with steel spoke wheels (107 cm diamter x 25 cm width) and rubber tires (57 cm diameter x 25 cm width) on alternate towers of each rig. Both were tested on different circles at the Muskegon project over a period of several months to compare their performance regarding rutting. There was no evidence of deeper ruts caused by either wheel type. However, the steel spoke wheels did indicate inferior performance in other areas. They often accumulated soil between the wheel cleats which reduced pulling traction resulting in rig misalignment. Mud within the outer wheel was carried up and deposited by rotation on the drive transmission. This contributed to failure of mechanical parts. Branches and roots became easily lodged between wheel spokes. As pointed out in the section covering operational problems, the steel spoke wheels were replaced with rubber tires early in the testing program because they caused frequent mechanical breakdowns. For this reason all data covering rut development were obtained with the use of rubber tire rigs.

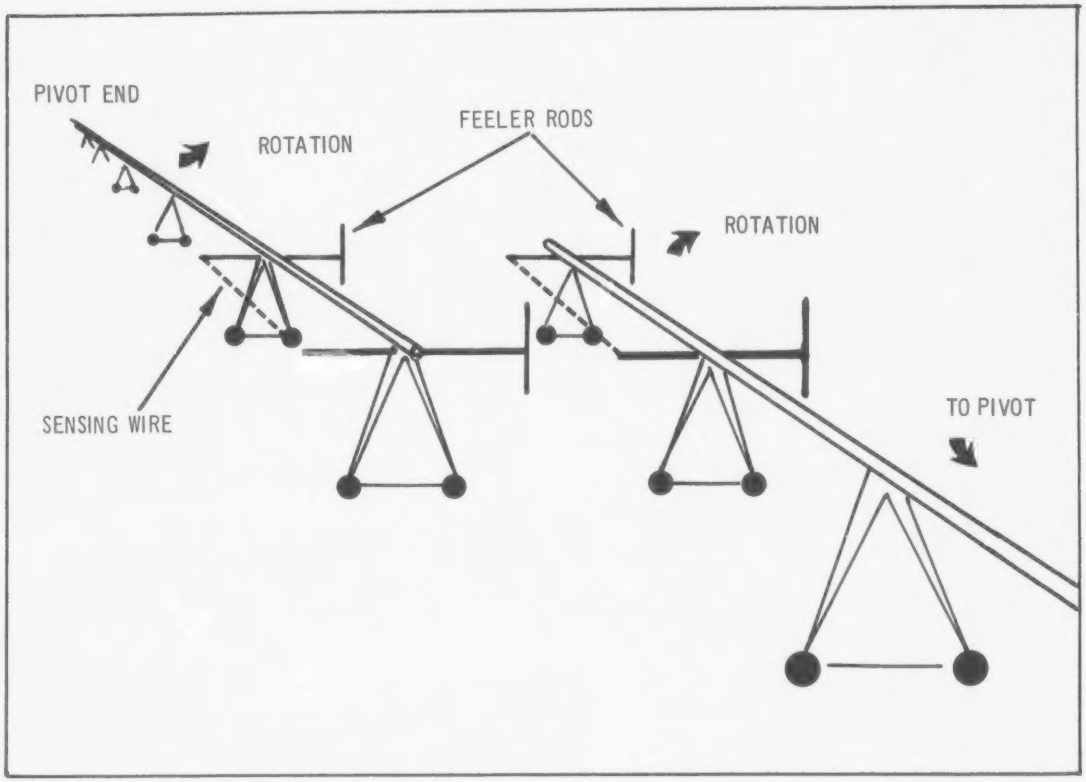


Figure 26. Anti-collision mechanism for overlapping irrigation machines

Conclusions

Rut formation data are plotted on Figure 27 for two soil types. The tests indicated that soil type was of more importance in rutting than the number of revolutions of the rig. Frequency of stopping-starting was not a significant factor.

Recommendations

All rigs should be equipped with rubber tires of a minimum width of 35 cm. Rigs operating over loamy-sand areas of high organic content should have tire paths filled with a suitable supportive base material. If done, this will require that these areas be farmed "in the round," for the padded paths would not be able to tolerate criss-crossing by heavy equipment.

SUMMARY

The optimization study identified the modifications necessary for the use of the rigs for wastewater irrigation.

Spraybar design is critical to uniform water application. Features which should be emphasized are: nozzle spacing for optimum coverage; nozzle size increase to permit operation at lower pressure and to form larger droplets, discouraging wind drift; adjustability of spraybars to minimize wind drift.

The rigs tested were structurally adequate to perform on the rugged terrain of the developing project site. The chain drives of the test rigs were subject to frequent breakdown and should be replaced with gear shaft-drive systems. Replacement was also indicated in the case of the steel wheels of the rigs: rubber tires of adequate flotation should be substituted to combat rut formation.

Anti-collision devices performed well in overlapping rigs and should be installed where necessary.

It was recommended that rigs not be operated during winter weather because of the problems of ice formation. All water lines should be equipped with proper valves and facilities for automatic drainage.

The Lockwood rig performance was superior to the Enresco.

At minimum, irrigation machines should be operated at rotation rates consistent with keeping surface soils moist and with achievement of application rates with the water infiltration capacity of the soil. Faster rates of rotation are preferred to achieve a more uniform soil moisture profile and longer moisture retention time for enhancement of wastewater nutrient reactions with soil and crop root systems.

Within limits, consistent with control of aerosol drift, operation of irrigation machines at higher nozzle pressures should be considered to achieve more uniform spray application of water.

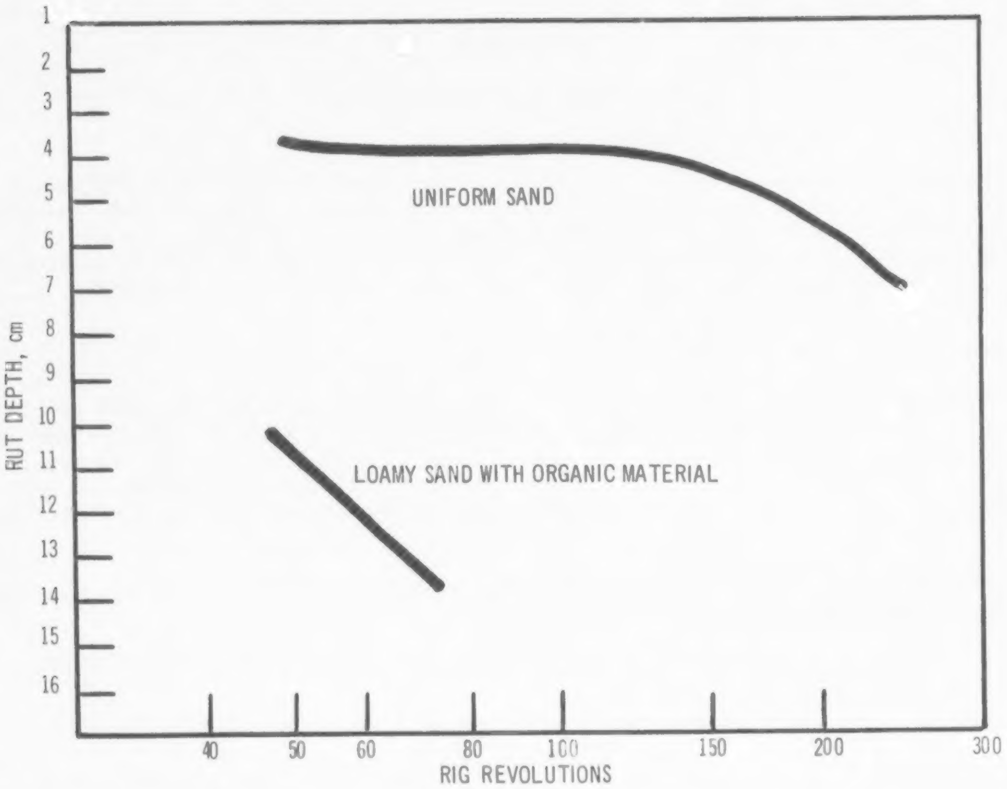


Figure 27. Rut depth produced in sand and loamy sand with rubber tires by the Enresco rig in Circle 39

SECTION 6

OPERATIONS AND MAINTENANCE

This section describes the total operations and maintenance experience from May 1973 through December, 1975, including the reliability of all mechanical-physical components. The discussions are arranged in the following order: collection, transport, treatment, disinfection, irrigation, and drainage. System operations and performance data discussed in subsequent Sections are available for reference and examination in the USEPA Water Quality Control Information System (STORET).

COLLECTION AND TRANSPORT

Ten lift stations throughout the metropolitan Muskegon area were available for pumping wastewater to the main pumping station, C-station, which pumped the total volume 18 km to the treatment site. Two stations, A-station in Laketon Township and J-station in Muskegon Township, were not in service in 1975 because the areas to be serviced by them were without a sanitary sewer system. In Norton Shores, a newly constructed sewer system was linked up with F-station for the first time in 1975.

Table 24 lists the stations in the Muskegon subsystem with their 1975 wastewater flow rates and their electrical power consumptions.

Table 24. 1975 LIFT STATION PUMPING QUANTITIES AND POWER CONSUMPTION

	Flow, TCM		
Lift station	Daily	Annual	Electrical power, KWH
A[a]	0	0	11,100
B	1.18	430	32,700
C	97.29	35,511	7,814,400
D	61.44	22,425	2,456,800
F[b]	0.34	10.5	14,700
G	5.28	1,927	169,200
H	5.49	2,004	30,403
J[a]	0	0	2,400
K	1.13	414	75,227
L	0.31	113	5,978
N	0.14	50.7	5,680

[a] Not in service

[b] Began continuous operation in September

Detailed discussions of maintenance requirements of the various stations are in Appendix B, but the major problems occurred at those stations pumping the largest volumes, stations C and D.

The listing of those municipalities and industries connected to the collection system with their respective discharge volumes for 1975 is in Table 25. A summary table of monthly flow volumes in TCMD for each month since startup of operations is in Appendix B, Table 1.

Table 25. USER WASTEWATER QUANTITIES

User	Start-up date	Daily volume, TCMD	Annual volume, TCM
City of Muskegon	5/10/73	27.63	10,086
City of Norton Shores	5/10/73	2.65	967
City of Roosevelt Park	5/10/73	2.65	967
City of Muskegon Heights	5/30/73	4.54	1,658
City of North Muskegon	6/ 9/73	1.14	415
S.D. Warren Company (pulp mill)	6/ 4/73	55.27	20,174
Story Chemical Corp.	4/18/74	3.41	1,244
	Total	97.29	35,511

Odor and Foam Control

The Muskegon project is not odor-free. During the early months of operation when all of the influent was domestic in origin, there was no significant odor. But as industrial waste constituted more and more of the influent profile, the severity of the odor problem increased proportionately. The reactions which produced the most offensive odors were those involving reduction of sulfur compounds, organic and inorganic.

Efforts were made to identify and isolate the odor-causing streams. Measures were taken at S.D. Warren Paper Co. to minimize reduced sulfur levels by mixing effluents with bleaching agents. Odor was substantially reduced, but in 1975 mechanical changes were made to the inlet flume of the biological treatment cell. Influent was introduced to the cell beneath water level, minimizing vaporization, and a permanent cover was constructed [illegible] encase the inlet flume. See Figure 29. These modifications in combination with altered modes of operation of the biological treatment cells were remarkably effective in cutting down odors. The evaluation was simple qualitative olfaction.

No odor problems have been associated with irrigation operations, and with the exception of the odoriferous sludge during spring turnover, the storage lagoons have been essentially complaint-free.

Aeration occasionally generated in the biological treatment cells large volumes of foam, caused by foaming agents that were thought to be lignins. Operation of two treatment cells at half capacity reduced the agitation and greatly reduced foam production.

TREATMENT

This phase includes biological treatment cells and equipment, storage lagoons, chlorination facility, irrigation pumping stations, irrigation machines, drainage pumping stations and outfalls.

Operations varied with season. During the winter months from December through March, wastewater was channeled through the biological treatment cells and into the storage lagoons for long-term impoundment. During the summer months from April through November, the water from the storage lagoons plus the aerated daily influent were used for irrigation, thus creating storage volume for the non-irrigation winter months. From either storage lagoon, water flows by gravity to the outlet lagoon and from there into a mixing chamber for chlorination. After chlorination, the effluent flows via open channels to two irrigation pumping stations, from which it is pumped to the circular irrigation areas.

Each aspect of this sequence is detailed below.

Biological Treatment Cells

The flow patterns and operation modes of the biological treatment cells were altered as more was learned about treatment efficiency. The patterns are summarized for years 1973 through 1975 in Table 26.

To reduce power consumption, only number 1 was operated in January, 1975. Aerated effluent was discharged into the east storage lagoon, and 2 and 3 were bypassed. With this operational mode, the removal of BOD was inadequate, so the pattern was changed to include cell 2. But the equipment equivalent of only one cell was used for both cells, six of the 12 aerators and three of the six mixers in each cell.

When after February, 1975, it was found that the dissolved oxygen level in cell 1 was near zero, the mode was again altered in March; eight aerators in cell 1 and four in cell 2, with three mixers in each, as before. This scheme in combination with doubled retention time maintained adequate levels of dissolved oxygen in each cell and provided satisfactory BOD removal.

Sludge was removed from the drained biological treatment cells in 1975. See Figure 28.

Using a front-end loader and a 12yd dump truck, the sludge was moved to the sandy area north of the treatment cells for drying. When dry, the sludge was loaded into a manure spreader and uniformly applied to the northeast half of circle 34, a very sandy area.

Table 26. OPERATIONAL MODES OF BIOLOGICAL TREATMENT CELLS, 1973-1975

Year/month	Biological treatment cell Cell Number 1	 Cell Number 2	 Cell Number 3
1973			
January	NO[a]	NO	NO
February	NO	NO	NO
March	NO	NO	NO
April	NO	NO	NO
May	Series	Series	Series
June	Series	Series	Series
July	Series	Series	Series
August	Series	Series	Series
September	Series/parallel	Series/parallel	Series/NO
October	Parallel	Parallel	NO
November	Series	Series	NO
December	Series	Series	NO
1974			
January	Series	Series	NO
February	Series	Series	NO
March	Series	Series	NO
April	Series	Series	NO
May	Series	Series	NO
June	Series	Series	NO
July	Series	Series	NO
August	Series/parallel	Series/parallel	NO
September	Parallel/series	Parallel/series	NO
October	Series	Series	NO
November	Series	Series	NO
December	Series	Series	NO
1975			
January	Series	NO	NO
Febraury	Series	Series	NO
March	Series	Series	NO
April	Series	Series	NO
May	Series	Series	NO
June	Series/NO	Series	NO/series
July	NO	Series	Series
August	NO	Series	Series
September	NO	Series	Series
October	Series	Series	NO
November	Series	Series/NO	NO
December	Series	NO	NO

[a] Non operating

Figure 28. Sludge removal in biological treatment cell Number 2, 1975

Equipment Maintenance –

The incidences of maintenance of the aerators and mixers in the three biological treatment cells are summarized in Table 27. More detailed descriptions are in Appendix B.

Only four of the 36 aerators, or 11 percent, required repair. Eight of the 18 mixers, or 44 percent, needed repair, most commonly because of loosening of the platform mounting bolts from vibration. Installation of additional steel bracing by the installation contractor provided greater rigidity, but, as indicated by the 1975 failures, the problem was not completely corrected. See Appendix B.

Table 27. EQUIPMENT MAINTENANCE IN BIOLOGICAL TREATMENT CELLS, 1973-1975

Apparatus/ number	Cell number 1	2	3
Aerator			
1	None	None	None
2	None	Motor leads	None
3	None	None	None
4	Moved to Whitehall	None	Returned from S.D.Warren Co.
5	None	None	Locked rotor
6	None	None	Noisy operation
7	None	None	None
8	None	None	None
9	None	Motor leads	None
10	None	None	None
11	None	None	None
12	None	None	None
Mixer			
1	Vibration	Vibration	None
2	Loose bolts	None	None
3	None	Noisy operation	Vibration
4	Sheared bolts	None	Vibration
5	None	None	None
6	None	Motor failure	None

Power Consumption –

From late 1973 through 1974, two of the three biological treatment cells were operated, and adequate BOD reduction was maintained. In 1975, with the equipment equivalent of one cell in operation, further BOD reduction was achieved, while simultaneously reducing electric power consumption. The breakdown by year of power consumption by the biological treatment cells is in Table 28, and it shows that though the system was operating only eight months in 1973, the KWH requirements were about 40 percent higher than for the full year of 1975.

Table 28. ELECTRIC POWER CONSUMPTION IN BIOLOGICAL TREATMENT CELLS, 1973-1975

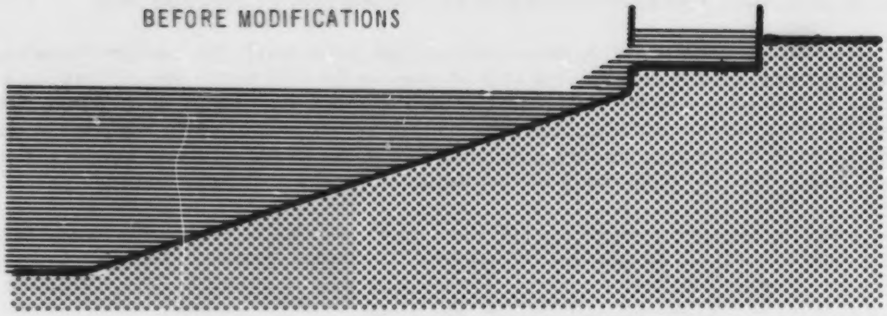
Cell number/Apparatus	1973, KWH[c]	1974, KWH	1975, KWH
Cell number 1			
Aerators[a]	3,152,736	3,885,521	2,959,471
Mixers[b]	1,328,400	2,001,648	899,157
Cell number 2			
Aerators	3,046,464	3,853,868	1,863,983
Mixers	1,328,400	1,963,874	708,248
Cell number 3			
Aerators	1,700,352	443,004	731,899
Mixers	649,440	527,723	218,606
Total	11,205,792	12,675,638	7,381,364

[a] 44.7 KW
[b] 37.2 KW
[c] Cells in operation eight months

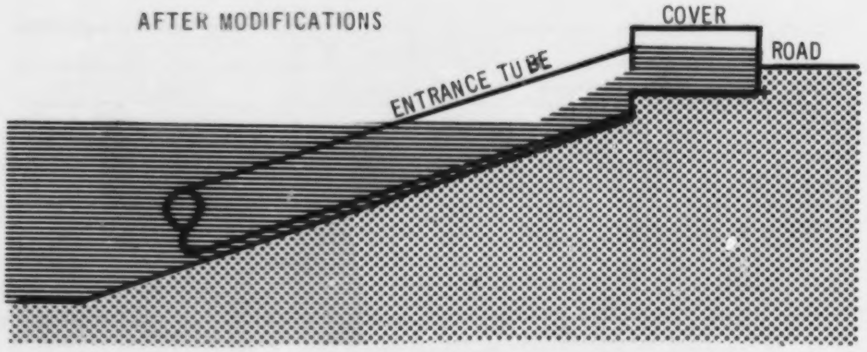
Inlet Flume Modification –

Raw influent pumped from C-station created odor problems at the point of entry into biological treatment cell number 1. In October, 1975, the inlet flume was covered for 40 meters at the opening, and an entrance tube, 1.5 meters in diameter and 12 meters long, was installed which directed the flow well below the water surface, thereby eliminating splash and droplet formation. The modifications are illustrated in Figure 29.

After installation, the odor was significantly reduced, but additional work is in progress to evaluate performance and to further minimize odor.



BEFORE MODIFICATIONS



AFTER MODIFICATIONS

Figure 29. Odor control cover and entrance tube on biological treatment cell No. 1

Storage Lagoons

Figure 30 graphically depicts storage lagoon water levels from 1973 through 1975.

Water levels during mid-May, 1974, were at design high water level, 210.3 meters elevation. This was due to the abnormally high accumulation of water in the 1973 winter and 1974 spring because of delays in construction of the irrigation rigs and water distribution pipelines. These delays extended into 1974, but the urgency of the lagoon water levels prompted the completion of some 20 irrigation rigs, and irrigation proceeded for about two weeks with rig endcaps removed to promote greater volume flow. This procedure was discontinued because of spotty flooding.

As an emergency measure, a temporary spillway was constructed to connect the irrigation channel to the drainage canal, providing a direct route from the storage lagoons to Mosquito Creek and bypassing the incomplete irrigation system. The spillway was completed in June, 1974, and was used to relieve the lagoon high water levels which crested at 210.6 meters.

Apprehension regarding the irrigation construction timetables meeting anticipated lagoon-emptying needs prompted construction of a second spillway, a permanent connection between the south irrigation channel and the central drainage ditch. See Figure 35. This spillway was used for one week in July, 1974, to lower lagoon levels to an elevation of 210.6 meters.

It was during July that the west lagoon was "isolated." The water quality was high enough to permit direct spill in the event the irrigation system – for whatever reasons – failed to spray the 1974 storage volume. Table 29 summarizes the discharge history of the storage lagoons.

Table 29. STORAGE LAGOON DISCHARGE HISTORY

	Discharge, TCM		
Year	From storage	To irrigation	To spillway[a]
1973	0	0	0
1974	32,024	28,799	3,225
1975	34,534	28,152	6,382

[a] From west storage lagoon only

As indicated in Figure 30, the level in the east lagoon was steadily lowered by irrigation, reaching its lowest level in November. Refilling was resumed with aerated effluent for winter impoundment.

In the case of the west lagoon, no water was used for irrigation in 1974, yet the level dropped 0.67 meters to an elevation of 209.4 meters in December. This loss was attributed to seepage through the unsealed lagoon bottom.

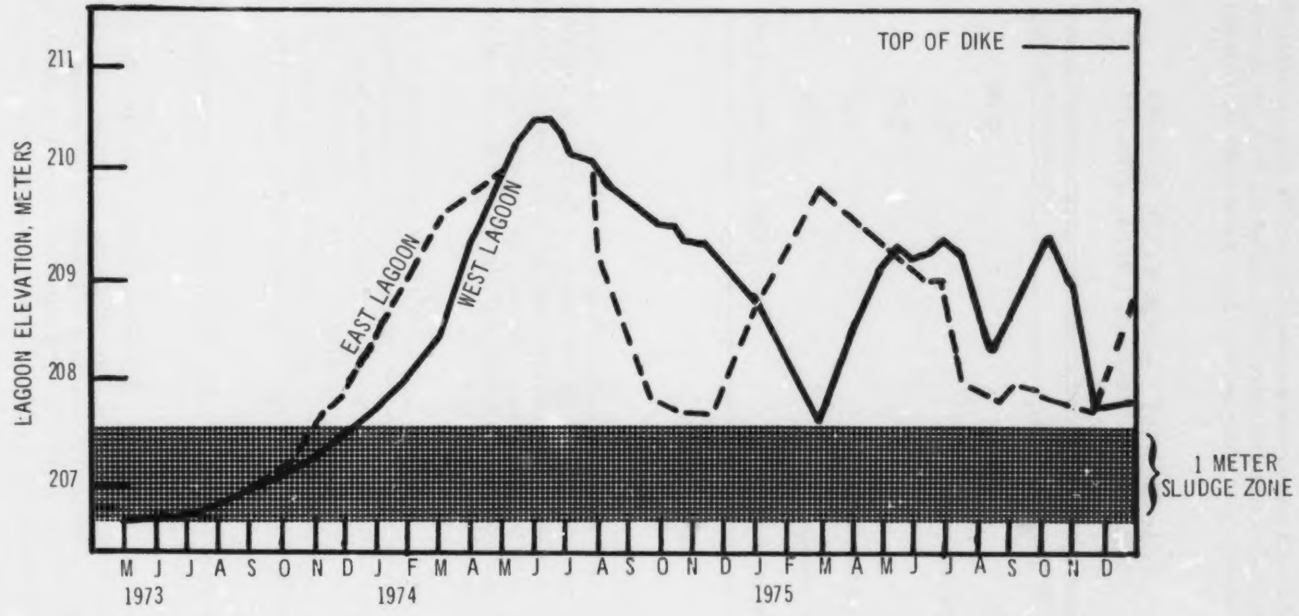


Figure 30. Storage lagoon water levels, 1973-1975

Direct spilling from the west lagoon was necessary to provide storage volume for the winter of 1974-1975. Water was spilled from December, 1974, to March, 1975, but the sustained impoundment had produced relatively good water quality. Some parameters are included in Table 30.

Table 30. WEST LAGOON WATER QUALITY
SPILLED TO MOSQUITO CREEK, 1974-1975

Parameter	Concentration, mg/l
BOD	5.00
Suspended solids	10.0
pH	7.50
Total phosphorus	0.50
Total nitrogen	2.00
Fecal coliform	(200 colonies/100 ml)

Interception Ditch Pumping–

The storage lagoons were designed without a bottom seal and were, therefore, expected to leak. As a control measure, an interception ditch was constructed along the outside perimeter of the lagoons which created a groundwater gradient toward the ditch from both the storage lagoon and the areas immediately adjacent to the ditch. The two pumping stations which return interception ditch water to the storage lagoons or to a discharge drainage ditch were installed along the northeast and south dikes, as indicated in Figure 31.

In 1973, it was discovered that the seepage water in the interception ditches was not polluted as expected but instead met Michigan discharge standards. It was assumed that the reason for this was a purification of the water as it migrated the 180 meters distance beneath the dikes. It was also deemed pointless to expend energy pumping clean water through the irrigation system, so one pump at each station was modified to discharge water away from the lagoons. In the event the quality of the interception ditch water deteriorated, the two remaining pumps could return the water to storage.

The quality did not deteriorate, however, and, through 1975, most interception ditch water was pumped directly to the drainage system.

The history of the levels of water in the interception ditches shows that the ditch volumes were directly proportional to the lagoon volumes, a relationship illustrated in Figures 32 and 33. In the case of both pumping stations, volumes pumped paralleled the average lagoon water levels, particularly during 1973-1974. In 1975, the proportionality seems less direct, but this may be due in large part to the fact that as the level in the east lagoon was rising, the west was dropping, and vice versa.

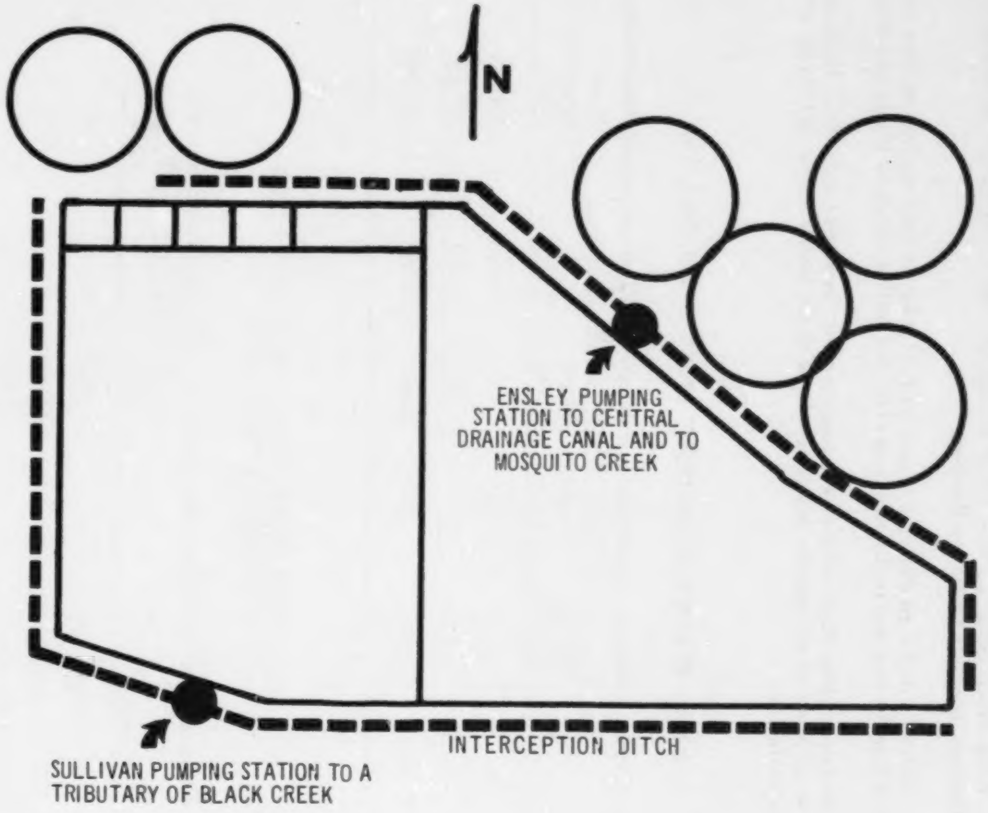

N
ENSLEY PUMPING STATION TO CENTRAL DRAINAGE CANAL AND TO MOSQUITO CREEK
INTERCEPTION DITCH
SULLIVAN PUMPING STATION TO A TRIBUTARY OF BLACK CREEK

Figure 31. Storage lagoon interception ditches and pump stations

A more thorough analysis of the influence of lagoon level on seepage rates and of overall groundwater hydraulics is under way by the U.S.G.S., the results of which are expected to reveal a macroscopic picture of the impact of the total system on the groundwater of the surrounding area.

The volumes of water discharged from the interception ditches to surface waters by the two pumping stations in 1975 are listed in Table 29. From Ensley Station, 99 percent of the water went to Mosquito Creek. From Sullivan Station, 53 percent went to Black Creek, and the rest was returned to the lagoon. Less was pumped to Black Creek because of fear of exceeding the hydraulic limitation of the tributary, possibly producing flooding.

Table 31 also indicated that a greater volume was pumped from the Sullivan Station than from Ensley. This difference was due to difference in size; the Sullivan ditch is longer and deeper.

In Table 32, the interception ditch volumes are compared for years 1974 and 1975. These data also reflect the influence of the storage lagoon levels, with the higher levels of 1974 paralleling greater pumping volumes.

Table 31. INTERCEPTION DITCH PUMPING VOLUMES, 1975

Pumping station	Pumping volumes, TCM Storage lagoons	 Mosquito Creek	 Black Creek	 Total	Power consumption, KWH
Ensley	100	9,796	0	9,896	454,793
Sullivan	5,879	0	6,561	12,441	477,195
Total	5,979	9,796	6,561	22,337	931,988

Table 32. COMPARISON OF INTERCEPTION DITCH PUMPING VOLUMES, 1974-1975

Pumped to -	Volume pumped, TCM 1974	 1975
East storage lagoon	2,148	100
West storage lagoon	12,603	5,880
Mosquito Creek	12,081	9,796
Black Creek	5,365	6,562
Total	32,197	22,338

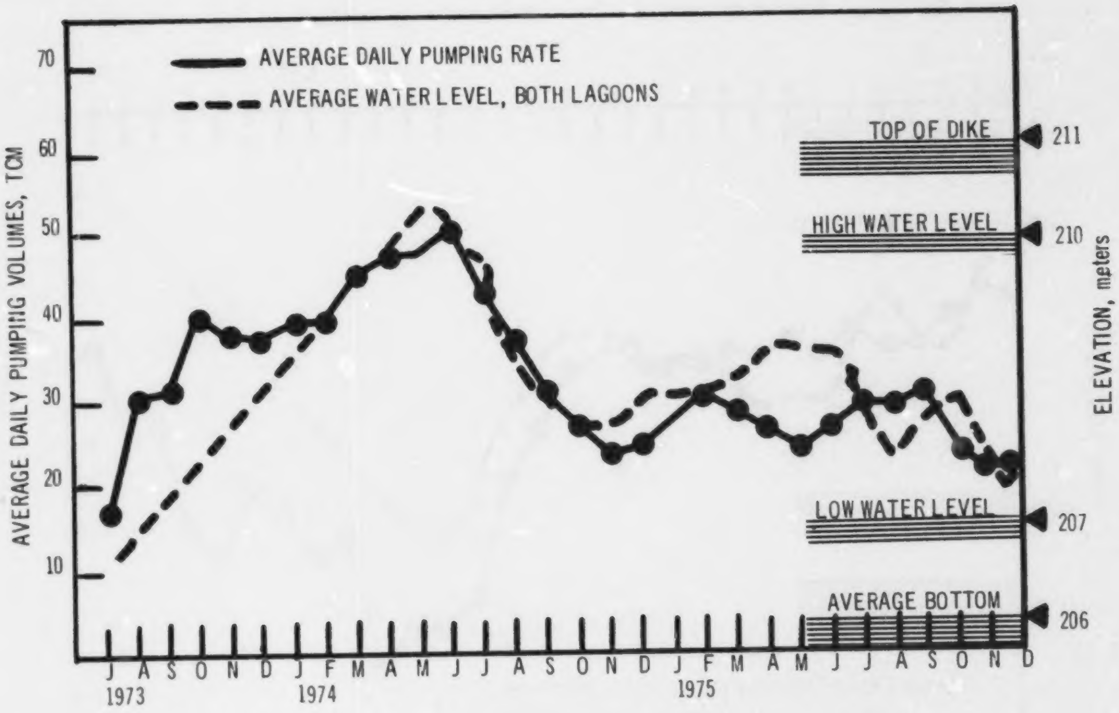


Figure 32. Interception ditch pumping volumes at Ensley station, 1973-1975

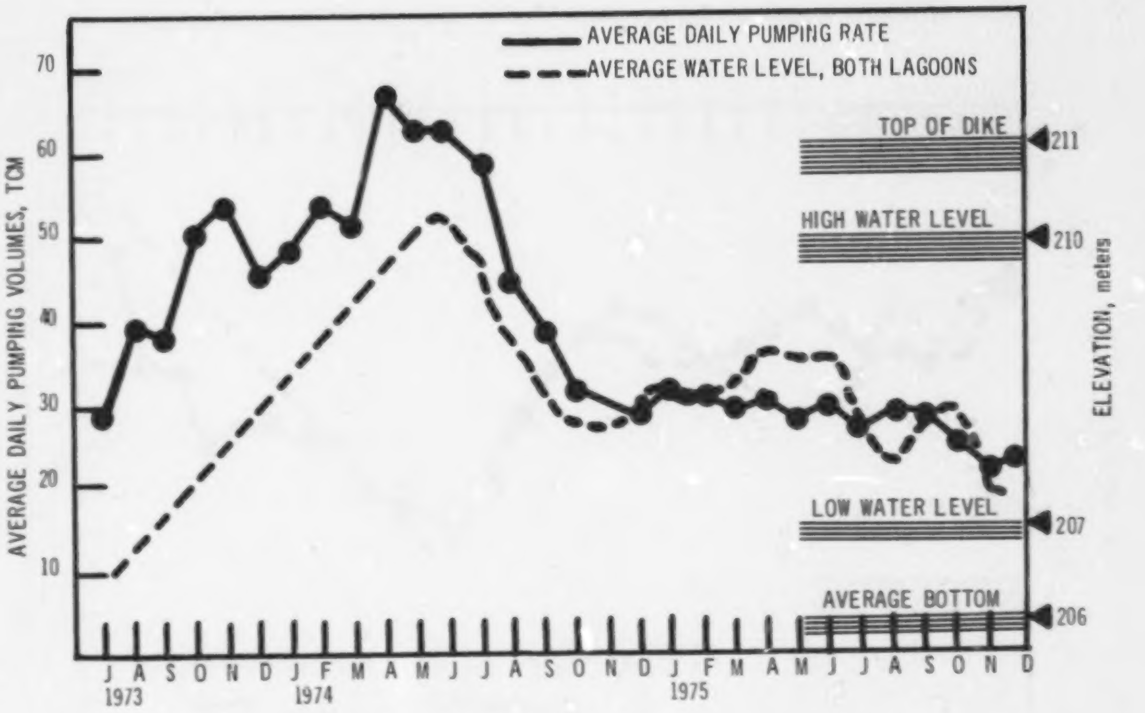


Figure 33. Interception ditch pumping volumes at Sullivan station, 1973-1975

Dike Repairs –

Each winter since 1973, the 20.3 cm thick soil cement designed to protect against wave action was damaged in some manner. In some cases, the surface cracked and allowed water to undermine the protective layer resulting in large cavities into which the soil cement eventually collapsed. In others the cement was spalled by erosion by water and ice, sometimes mildly, involving only the top few centimeters of cement, and other times severely eroding the cement completely away and leaving the sandy dike vulnerable to washout.

In no instance did any water escape from the lagoon as a result of the damage to the soil cement layer. Neither was there any evidence of increased seepage through the dike, even though the latter was comprised of compacted sand.

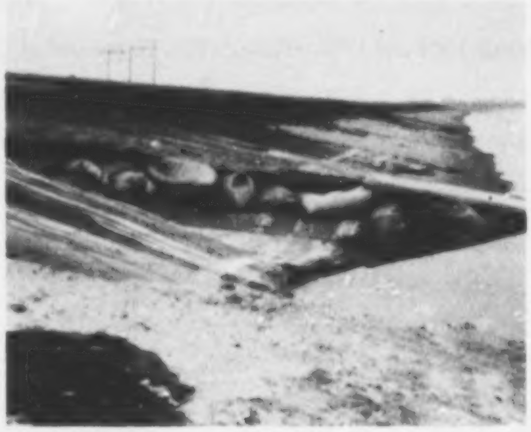


Figure 34. Dike slope protection damage on northeast wall of the east storage lagoon

Severe damage was usually restricted to surface areas ranging from one to ten square meters, but light spalling often occurred in stretches of a hundred meters along the dike. Most damage was along the northeast dike of the east storage lagoon, with lesser amounts along the north and center dikes in the west lagoon. The cause was attributed to the prevailing southwesterly winds, especially in the spring when ice and waves beat against the dikes.

Initial temporary repairs consisted of dumping riprap in eroded areas to break wave action and to reduce further erosion. During the high water of 1974, the local Civil Defense unit sandbagged the damaged areas. In October, 1974, soon as the east lagoon water level permitted, permanent repairs were begun. All temporary materials and debris were removed, and sand was compacted in the cavities, followed by concrete to a thickness of 20 cm. Less deep cavities were sealed with asphalt.

Because of high water in the west lagoon, only partial repairs were done in 1974, and when the water dropped to a workable level, cold weather and snow interfered. Repairs here were postponed until the spring of 1975. Only 110 cubic meters of concrete were poured in 1974.

During the winter of 1974-1975, the dike damage again was concentrated along the northern dike of the east lagoon and the center dike of the west lagoon, affecting primarily those areas patched the previous fall. Water undermining with subsequent collapse was common. More spalling and more erosion was found. It was suspected that the irrigular thicknesses of the soil-cement repairs was a factor contributing to the redamaged areas.

In September, 1975, repairs on the dikes of the wast lagoon, the most severely damaged, were begun. Again, riprap and debris were cleared away, and special efforts were made to prepare the holes to secure a better bond with the new parchwork. All sand was watered down to increase compaction. After adding about 15 cm of gravel for a patch base, the soil-cement perimeter of the hole was wetted down prior to pouring fresh concrete. In the east lagoon, about 100 cubic meters of concrete were poured and about 47 cubic meters in the west.

Disinfection by Chlorination

As the wastewater was discharged from the outlet lagoon, a concentrated chlorine solution was injected into the stream. Chlorine contact time was 30 minutes. After injection, the water flowed in a 1300 meter open channel at a rate of 2.75 km/hr before reaching the irrigation pumping stations.

Table 33 shows the amounts of chlorine used during 1974 and 1975. During 1974, 73 percent of

Table 33. MONTHLY LAGOON DISCHARGE VOLUMES AND CHLORINATION AMOUNTS, 1974-1975

Year/month	Storage discharge, TCM	Quantity disinfected, TCM	Chlorine used, kg	Average Cl_2 concentration, mg/l
1974				
April	0	0	0	0
May	276	0	0	0
June	4,474	0	0	0
July	6,999	5,258	23,637	4.50
August	6,833	6,833	52,674	7.00
September	5,008	5,008	41,506	7.30
October	4,028	4,028	34,997	8.70
November	2,222	2,222	23,873	10.7
December	2,184	0	0	0
[1974 subtotal]	[31,024]	[23,348]	[176,687]	[7.60]
[Percent]	[100]	[73]		
1975				
January	2,725	0	0	0
February	3,305	0	0	0
March	352	0	0	0
April	1,049	0	0	0
May	2,604	0	0	0
June	5,235	216	1,527	7.10
July	5,035	5,035	28,967	5.80
August	4,137	4,137	29,781	7.20
September	269	269	1,959	7.30
October	4,561	76	1,212	16.0
November	5,273	0	0	0
December	0	0	0	0
[1975 subtotal]	[34,545]	[9,733]	[63,446]	[6.50]
[Percent]	[100]	[28]		

the water discharged from the storage lagoons had an average dosage of 7.6 mg/l; during 1975, 28 percent of the discharge received 6.5 mg/l. The early parts of both years had direct discharge unchlorinated because the long impoundment had produced high quality water. Chlorination began July 8, 1974, with irrigation water from the east lagoon and continued until November when the east lagoon was emptied. The pattern was repeated in 1975 with no chlorination for the long-impounded west lagoon and chlorination for irrigation water taken from the biological treatment cells. After shutdown for harvest in September, the procedure was resumed for two days in October for post-harvest irrigation. For the remainder of the 1975 irrigation season, chlorination was discontinued because the irrigation mode was changed to permit water discharge from the rigs very close to the ground.

Irrigation System

The irrigation system consists of the irrigation canals which connect the storage lagoons and the irrigation pumping stations; the irrigation pumping stations which supply water to the rigs; the pressure pipe distribution network which connects pumping stations to each irrigation rig; and the center-pivot irrigation rigs.

Irrigation Canals –

Two trapezoidal canals, 1.5m wide at the base and 1.5m deep, supply water to the two pumping stations. Designated as the north and south canals, they are 1210m and 2890m long, respectively, and are sealed with a lining of 0.05mm PVC sheeting under about 30 cm of sand. The sand serves to shield the plastic from UV radiations.

Under the threat of the high lagoon levels of May, 1974, the canals were modified by the construction of spillways which facilitated direct discharge to the drainage system. These spillways are described in the discussion of the storage lagoons and are indicated in Figure 35.

During the 1974 irrigation season, there were three washouts near the north spillway involving canal overflow into the main drainage ditch. They were due to inexperienced personnel and/or electrical problems, but corrective action during the 1974-1975 winter prevented further occurrences in 1975. A new overflow spillway was constructed with concrete headwall and adjustable weir boards across the aperture.

Irrigation Pumping Stations –

The two irrigation pumping stations which supply water to the irrigation rigs are located at the ends of the irrigation canals, as indicated in Figure 23. The north station has five 188 KW pumps on each of two headers, designated as the north and south headers. The north header, with a delivery capacity of 118 TCMD, supplies water to 16 irrigation machines in circles 1-14, 54 and 55. The south header (of the north station) has a capacity of 99 TCMD and supplies 12 rigs in circles 15-26. See Figure 36.

The south irrigation pumping station has eleven pumps divided between two headers, also designated the north and south headers. On the north header are four 75 KW pumps with a delivery capacity of 42 TCMD which supply rigs, 27, 28, 29, 34 and 35. On the south header are seven 188 KW pumps of a delivery capacity of 167 TCMD which supply the remaining 21 rigs.

The sequence during which the stations and various headers were put into operation from May, 1974, forward was, in large part, determined by the timetables of construction of the pressure pipe distribution system and the irrigation rigs themselves.

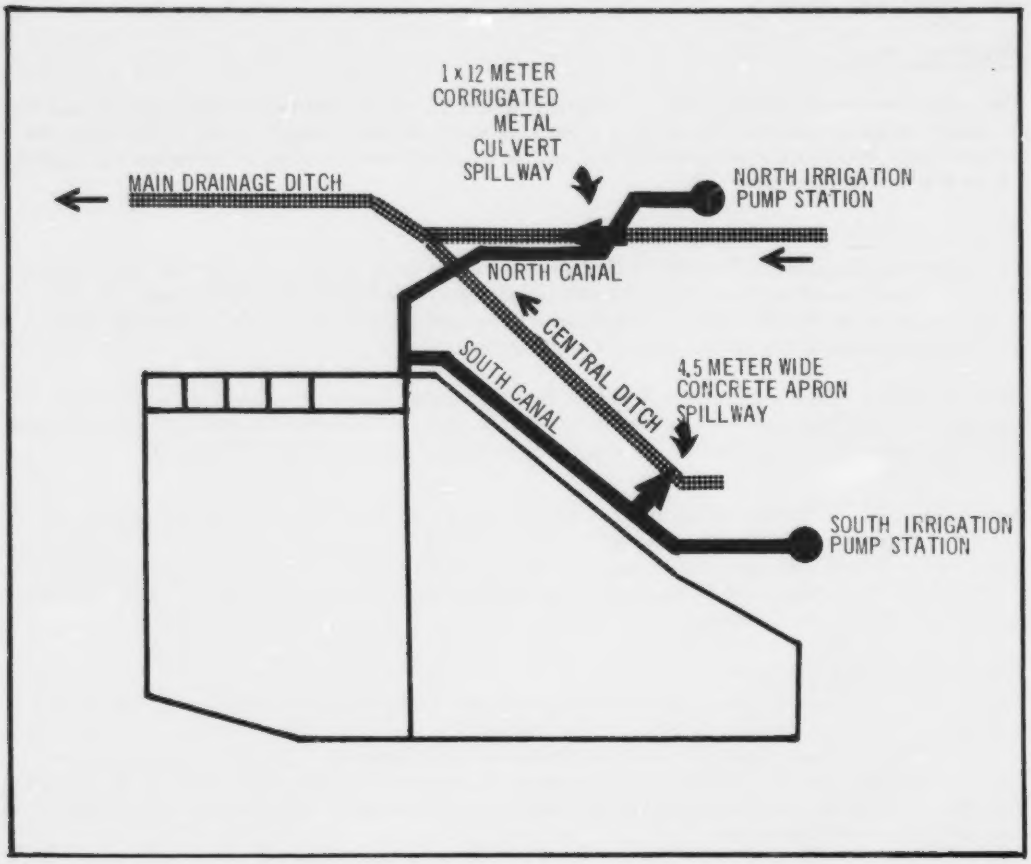


Figure 35. Irrigation canals with spillways and pump stations

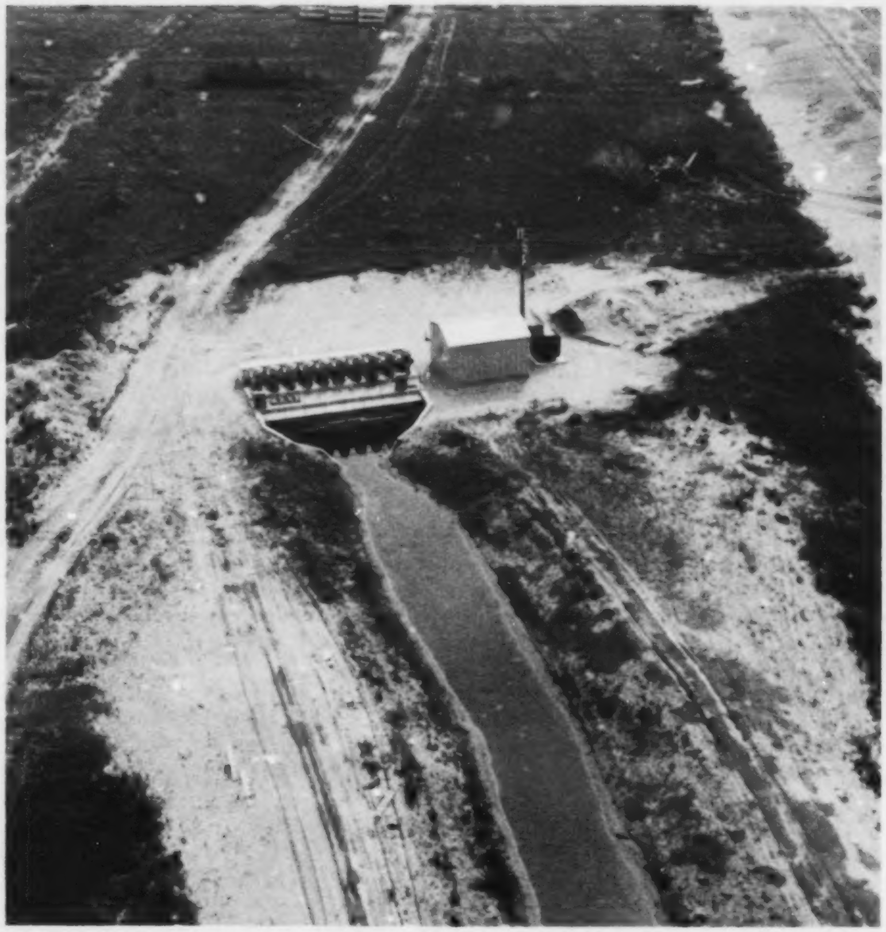


Figure 36. North irrigation pumping station with ten 250hp pumps.

Table 34 shows the volumes of water pumped by the irrigation stations during 1974 and 1975. Despite the late start in 1974, more water was pumped than in 1975. This was due to the high water in the lagoons, forcing pumping of irrigation water in order to minimize spillage to Mosquito Creek. The six weeks of harvest-irrigation shutdown in 1975 was not feasible in 1974.

During 1974-1975, about two-thirds of the total irrigation water was pumped by the north station. This difference was due to the late start-up of the south station in 1974 and, more important, due to the high permeability of the soils serviced by the north station, permitting almost continuous irrigation. In the south, irrigation was stopped to allow for field drying.

The maintenance requirements of the irrigation pump stations were minor; specifics are listed in Appendix B, Table 2.

Table 34. IRRIGATION PUMPING STATION VOLUMES, 1974-1975

	Volume pumped, TCMD				
	North station		South station		
Year	North header	South header	North header	South header	Total pumped
1974	11,901	7,480	5,016	4,402	28,799
[Percent]	[41]	[26]	[18]	[15]	[100]
1975	12,121	6,935	3,725	5,371	28,152
[Percent]	[43]	[25]	[13]	[19]	[100]

Pressure Pipes for Irrigation Distribution –
Delays in the completion of construction of this pipe network were in large measure responsible for the holdup of WMS operations from May, 1973, through May, 1974.

Causes for the delays were many and varied, including abnormally high groundwater, a labor strike, and about 90 failures of the asbestos-cement pipe.

These pipe failures were of three types: beam fracture due to differential settlement and aggravated by water hammer stresses during operations; rupture caused by water hammer during filling or during routine operation; and collar failure at points of small leaks beneath the gasket, gradually eroding pipe material. About 46 percent of the breaks were simple rupture, 30 percent collar involvement, and 24 percent beam collapse. See Figure 37.

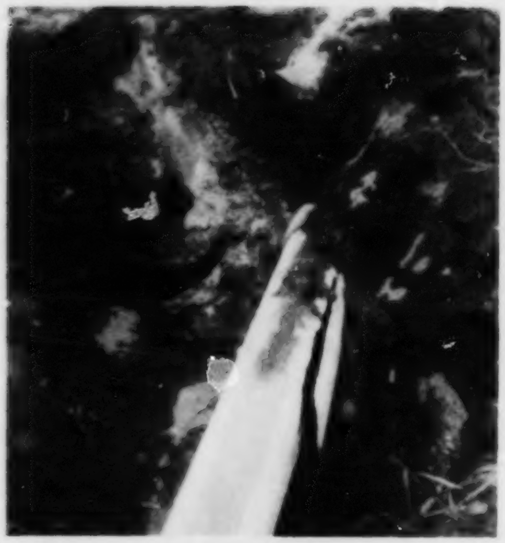


Figure 37. Ruptured irrigation pressure pipe, 30.5 cm diameter

Pipe failure drastically interfered with operations. The network was not equipped with valves which would permit isolation of a given segment in the event of a rupture, so that a single pipe failure forced the shutdown of up to 16 rigs until the repair was completed.

A major cause seemed to be the pressure surges in the pipe with the closure of the butterfly valves at the rigs. From a constant operating range of 3 kg/cm, pressures increased to 10 kg/cm. When timers were installed on the butterfly valves to delay closure, surge pressures were reduced to 2-3 kg/cm. Despite this measure, however, pipe failure recurred throughout the 1974 irrigation season.

Isolation valves were installed in 1974 at major junctions throughout the network to minimize rig shutdown.

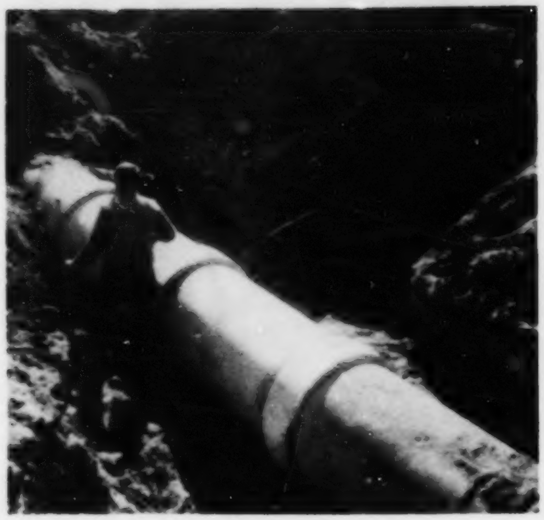


Figure 38. Repair in break of mainline pipe, 1 meter diameter

During the 1975 irrigation season, only nine pipe failures were experienced, suggesting that the measures taken in 1974 were adequate. All repairs were done by the installation contractors, and, in 1975, no replacement sections of pipe malfunctioned.

Buried Electrical Cable –

By the end of 1974, eighteen irrigation rigs were inoperable because of faults in the buried cable supplying power. Over 15,000 meters of cable were examined, both by electrical detection equipment and by excavation, and problems seemed to fall in three categories: (a) insulation burned away and aluminum conductor severely corroded or melted, (b) aluminum conductors disintegrated, and (c) no readily visible damage but function impaired.

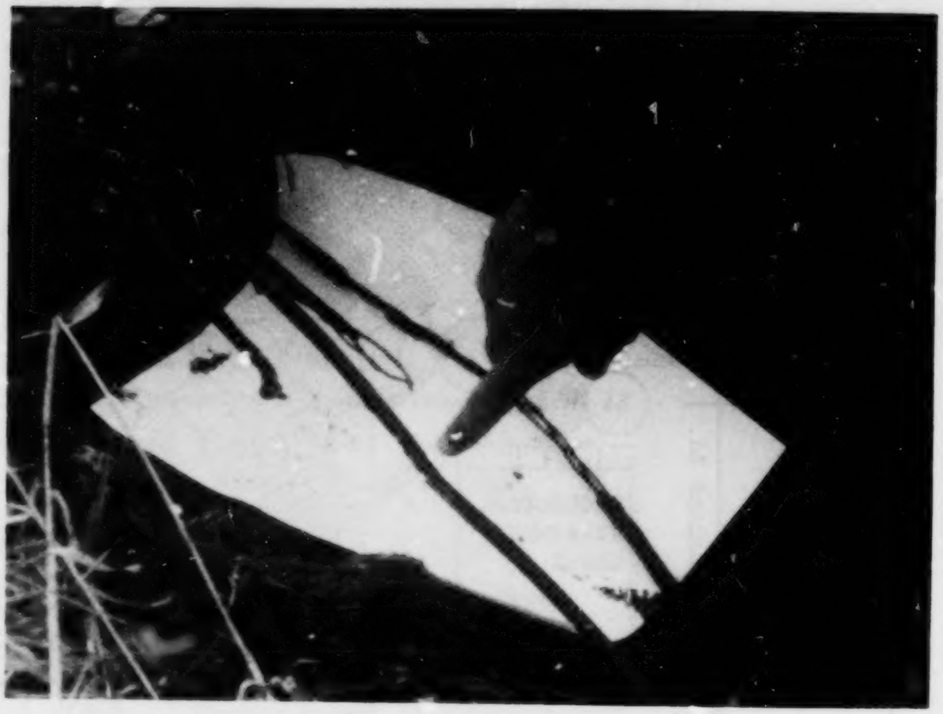


Figure 39. Unearthed faulty cable typical of early power supply malfunction

Radical repairs of the system were indicated. Bids were taken for the overhauling of the cable system, and in March, 1975, the bid of $300,000 was accepted. As of April 1, 1975, the number of rigs without power was 30; these are indicated in Figure 40.

The evaluation of the total rigs shut down for reasons of defective cables included three general categories: replacement of major portions of cable with copper conductors; repair of short segments by splicing; and rigs down because of dependent electrical connections in either of the above categories. Table 35 itemizes rigs shut down due to these failures.

All cable repairs were finished by June 15, 1975, in time to irrigate the 1975 corn crop.

The causes of the cable faults were only speculated upon: questionable engineering design, defective supplies from the manufacturers, and major lightning damage were cited. Lightning arrestors are being installed at critical locations, but other explanations were sought. However, investigations in 1976 indicated lightning to be the major cause.

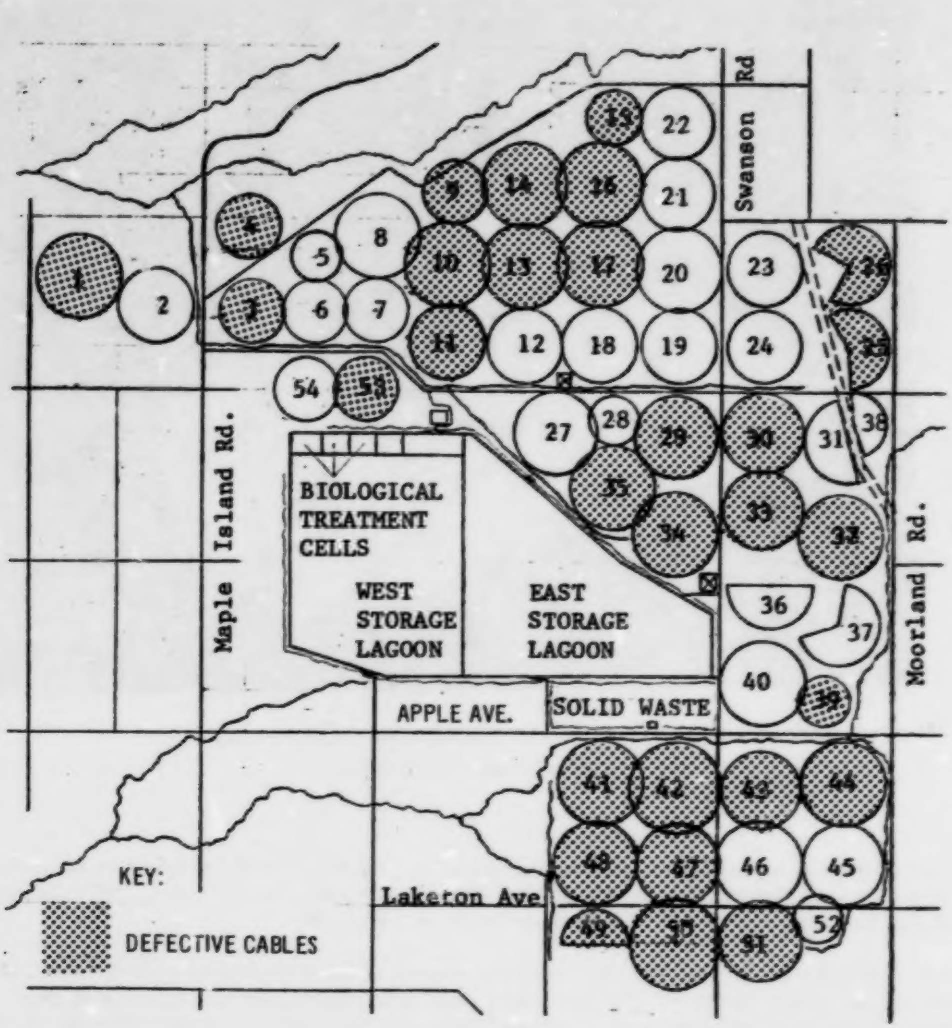


Figure 40. Rigs with Defective Electrical Cables

Table 35. ELECTRICAL CABLE ANALYSIS

Rig No.	Complete cable replacement, m	Spliced faults, meters	Power dependent on rig No.
1		6	
3	600		
4	700		
9	600		
10	650		
11	400		
13	700		
14			13
15	600		
16	700		
17	700		
25		6	
26		3	
29		200	
30	400		
32		200	
33		6	
34		200	
35		60	
39		12	
41			48
42	700		
43		6	
44		3	
47			48
48		20	
49			48
50			48
51		3	
53		15	
Total	6,750	740	

Irrigation Rigs –

The 54 center-pivot rigs vary in size, but each delivers an average of 6.8 TCMD on 40 ha. During the 20 hours needed to complete one revolution at 100 percent timer setting, about 1.5 cm of wastewater is applied.

Operating efficiency of the irrigation rig system in 1974 was low. Because of the many delays, only 29 rigs were available for use in late May, 1974, and not until late July was the total irrigation system ready for operations. On the best day in 1974, the largest number of rigs functioning at one time was 42, and the average number was 30.

In addition to the pipe and cable problems, the rigs in the eastern and southern areas of the site regularly bogged down in the heavy soils. The smaller tires – which had been substituted for the design-specified size – were unsatisfactory. Larger tires were installed by the 1975 season.

Generally, 1975 was a more efficient year. On the best day, 48 rigs were operable, and on the average 40 rigs were operable, a direct reflection of fewer power/hydraulic problems.

Water application by rigs – In Table 36, irrigation rig parameters are compared for 1974 and 1975. Although the amounts of water irrigated appear nearly the same, the modes of operation were different. The 1974 irrigation period was characterized by more continuous irrigation, uninterrupted by fertigation, rainstorm downtime, or downtime for harvest. In 1975, without the pressures of high lagoon levels, irrigation was more "controlled" and more consistent with crop needs.

Table 36. IRRIGATION RIG WATER APPLICATION, 1974-1975

Year	Rig hours	Rig days	TCM sprayed	Hectares irrigated	cm applied
1974	100,800	4,200	28,799	2,112	7,308
[Average for 54 rigs]	[1,867]	[78]	[533]	[39]	[135]
1975	102,252	4,260	28,152	2,071	7,282
[Average for 54 rigs]	[1,894]	[79]	[521]	[38]	[135]

Figures 41 and 42 illustrate the amount of wastewater applied per irrigation circle per year for 1974 and 1975. The volumes applied were regionally similar, more in the north, less in the south, again reflecting the higher permeability of the northern circles.

Rigs stuck in the mud – The specified tires for the rigs were 6-ply 37 x 60 cm. Because the size was unavailable at the time, 27.5 x 60 cm recapped 12-ply tires were substituted, with a "guarantee" of equal flotation. They stuck in the mud. The rig contractors replaced again with 32.5 x 55 cm, and they stuck in the mud. In August, 1975, thirteen rigs received 37 x 60 cm tires, and although the downtime was greatly reduced, some rigs continued to bog down in the mud. See Figure 43.

On rig 46, a faster gear box was installed in 1975 which increased the speed of rig revolution by a factor of two. The field became less saturated, and this approach is under consideration for other circles.

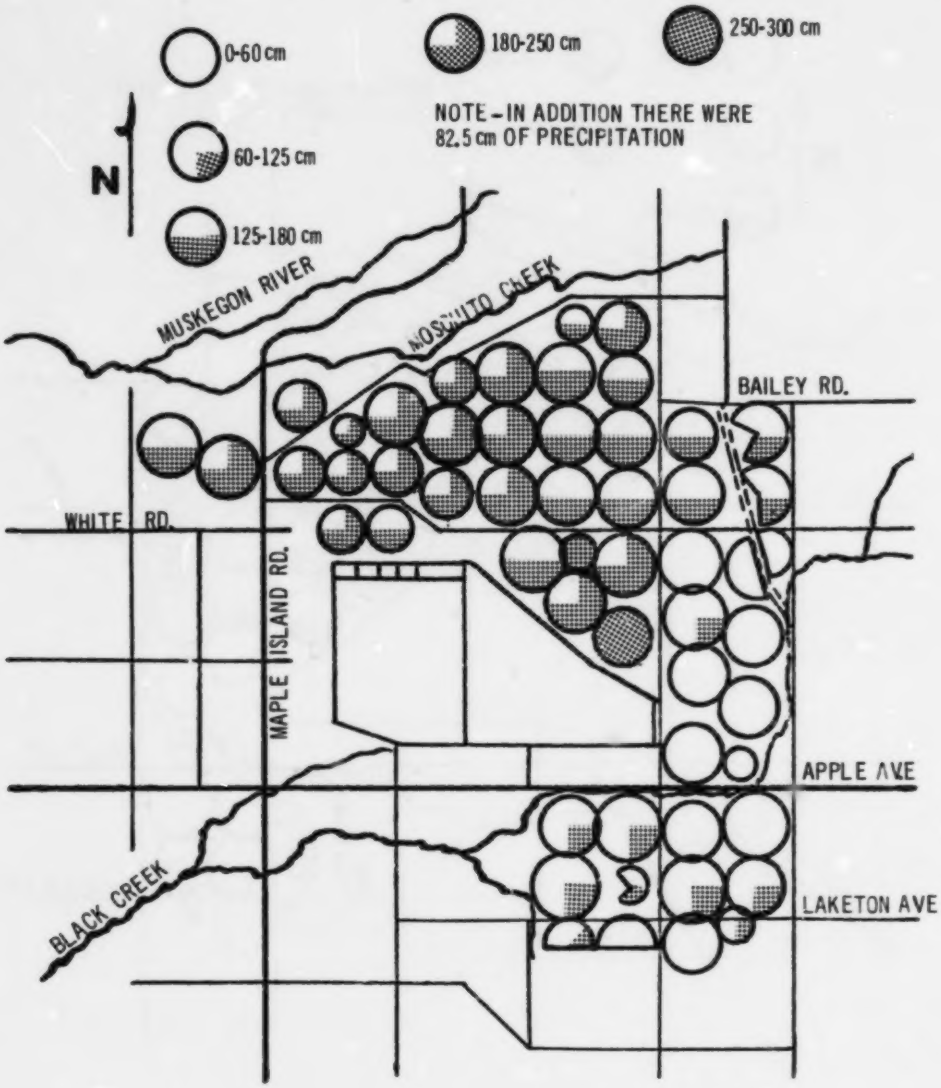


Figure 41. Water applied by irrigation, 1974

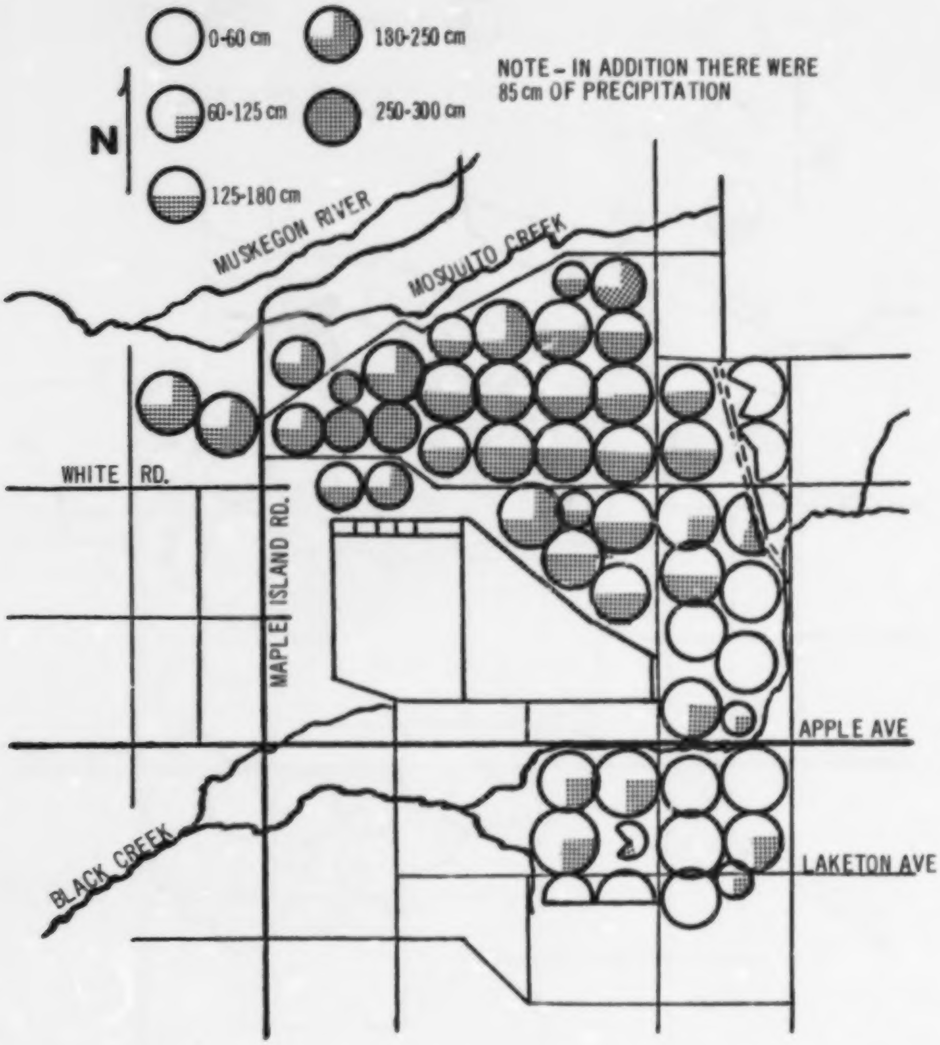


Figure 42. Water applied by irrigation, 1975

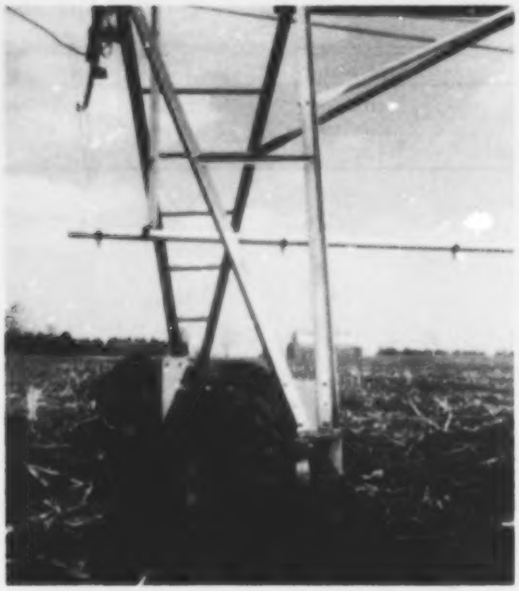


Figure 43. Rig tires deeply stuck in mud

Irrigation rig maintenance – The average rig operating time for 1974-1975 was less than 80 days for irrigation seasons of 200-plus days. In 1975, record-keeping was begun on cause of downtime, and these causes were: mechanical or electrical malfunction, shutdown at farm management request, and shutdown because of extremely wet fields.

The mechanical-electrical problems most frequently encountered were:

1. Readjustment of the alignment and safety shutdown system
2. Replacement of the electric motors located at each tower
3. Replacement of the motor gear boxes
4. Replacement of the wheel gear boxes
5. Trouble-shooting the electric control box
6. Repair or replacement of the drive shaft universals
7. Repair of structural damage
8. Repair of automatic water valve at pivot
9. Repair or replacement of flat tires
10. Repair of pressure pipe breaks
11. Repair of buried electrical line faults

But as may be seen in Table 37, the overall percentage of downtime attributed to mechanical-electrical failure was eight percent of total rig downtime. The particularly high downtime due to farm requests in the triangle was due to ongoing agricultural experiments; and in the case of the east and south circles, the soil types are mucky. Farm requests included shutdown for a six week harvest drydown.

Table 37. IRRIGATION RIG PERFORMANCE, 1975

	Operating (irrigating) or downtime, percent				
Status	Overall	Northwest circles 1-14, 53, 54	Northeast circles 15-26	Triangle circles 27-29, 34, 35	East & south circles
Operating (irrigating)	40	58	45	45	20
Down due to:					
Farm request	35	24	31	39	46
Wet field	10	5	3	7	20
Mechanical/ electrical	8	6	15[a]	6	6
Electric lines	7	7	6	3	8
Total	100	100	100	100	100

[a] Water valve failure; no crop planted in circle 26

Nozzle-plugging in rigs – Sand, twigs, straw, fish, frogs and bird nests all contributed to nozzle-plugging. Ramifications included: reduction of corn production up to 50 percent in some circles; reduced volume-flow of wastewater; outlay of manpower for cleaning nozzles; and increased stress on the pressure pipeline distribution system. See Figures 44 and 45. Extra men were hired in 1974 specifically to obviate this problem, and mainline pipes and bars were regularly flushed with rig end caps off. But plugging remained a nuisance throughout 1975.

In the fall of 1975, a filter was installed on the supply pipe to rig 22 which effectively prevented plugging: however, the filter itself encrusted and required frequent flushing. At the pivot, undesirable ponding occurred.

Emphasis shifted onto the source of the plugging debris. Modifications to the irrigation canals are being considered which would prevent objectionable materials from entering the pumps.

Drainage Systems –

Table 38 shows the estimated discharge volumes through those portals which were monitored. Measuring drainage volume over most of the project property was difficult. Although the volumes discharged from the lagoon and Ensley ditch were documented with pumping records and USGS gauging stations in drainage canals measured those flow columns, there are extensive portions of the northern boundary which are naturally drained to Mosquito Creek, with no quantitation possible.

Problems associated with the wells were legion. In most cases, the drainage rates of the pumps were greater than the recharge rates of the wells. During pumping, the well casings were dewatered in a matter of seconds, even with the discharge valves throttled down, resulting in too frequent pump cycling. This eventually rendered the pumps inoperable and, in some instances, permanently damaged the motors. The controls were modified to avoid the frequent cycling, but

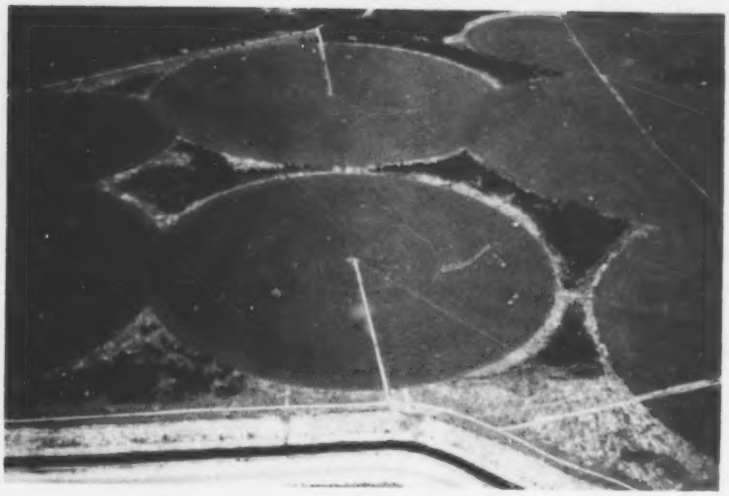


Figure 44. Irrigation circles with uniform crop coverage, indicating properly functioning rigs and satisfactory soil

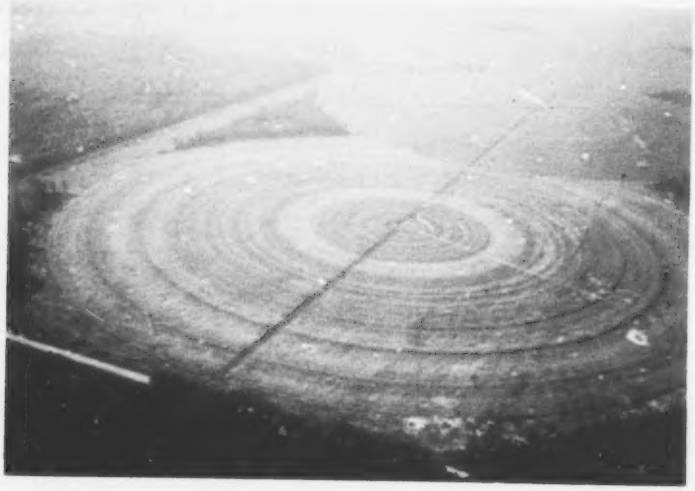


Figure 45. Circle 22 showing "donuts" resulting from estimated 90 percent nozzle plugging

this measure inhibited the intended function of the wells. Consequently, areas were not properly drained. Circles drained by wells became inundated, especially during spring thaw.

Corrective measures are being tried.

Installation of 1.1 KW pumps which more closely matched the recharge of the wells met with some success. But further improvements in the drainage system – particularly in the southern and eastern areas of the site – should include installation of additional drain pipes. The system is under study for further improvements.

Table 38. DRAINAGE SYSTEM DISCHARGE VOLUMES, 1973-1975

	Year, TCM		
Receiving waters and drainage source	1973	1974	1975
Mosquito Creek			
Drain pipes[a]	16,580	23,027	25,207
Wells [b]	0	0	(est.) 0
Ensley pump station	7,631	12,079	9,797
Total	24,211	35,106	35,193
Black Creek			
Drain pipes (Laketon Pump Station)	5,186	7,378	6,447
Wells (circles 36, 37, 39, and 40)	0	(est.) 378	(est.) 378
Sullivan Pump Station	5,697	5,364	6,560
Total	10,883	13,120	13,385

[a] Outfall discharge minus wells and Ensley Pump Station

[b] No discharge due to mechanical-electrical problems

MANPOWER REQUIREMENTS

A breakdown of the 1975 manpower requirements for the various WMS operations appears in Table 39.

Table 39. 1975 WMS FULLTIME AND PART-TIME LABOR REQUIREMENTS

Category		Manpower, Number of persons
Full time		
Collection and transmission		9
Aeration and storage		3
Irrigation		4
Drainage ditches (shift operators)		4
Farming		8
Laboratory and monitoring		9
Administration		3
Total		40
Part time		
Janitorial		2
Seasonal	up to	8
Total		10

SECTION 7

TREATMENT PERFORMANCE

INTRODUCTION

The treatment performance model at WMS is based upon the concept of the Muskegon project as a closed flowing system; that is, it has a single inlet and two points of outlet. By monitoring water quality at various stages along the "flowing system," – such as, biological treatment cells, lagoon storage, chlorinating, drainagepipes, outfalls to surface waters, and groundwater wells – a broad picture of the effectiveness of wastewater renovation is obtained. Other considerations are the relationships between treatment efficacy and energy input, particularly during biological treatment and lagoon impoundment. Soil dynamics and crop influence are, of course, important to treatment performance but are discussed in the section on agricultural productivity.

SAMPLING PROCEDURE AND LOCATION

Sampling sites were selected to monitor the water quality through the system from influent to final discharge at the drainage outfalls. The linear arrangement of the treatment facilities allowed the tracing of changes between each sampling location. Table 40 shows the frequency of sampling and number of samples, and Figure 46 shows the sampling locations.

Parameters and Methods of Analysis

The parameters routinely measured in this study were selected on the basis of their significance for complete water quality characterizations. They are listed in Table 41.

During the selection of parameters, consultations were sought with various groups concerned with public health, such as the Federal Food and Drug Administration, the United States Department of Agriculture and the Michigan Department of Public Health. It was deemed important to know what effect these parameters would have both on agricultural productivity and on the subsequent receiving water. Beside those listed in Table 41 which were routinely monitored, analyses were done on some additional screening parameters which are listed in the methods of analysis below.

The methods of analysis were selected from *Standard Methods* and other accepted chemical analytical procedures.

Table 40. SAMPLING LOCATION

Sample location	Code	Frequency	Number of samples
Influent at flume			
(1) Inlet to treatment cells	INF	Daily[b]	2[d]
Biological treatment			
(1) Leaving aerated lagoon 1	Cell 1	Daily	2
(2) Leaving aerated lagoon 2	Cell 2	Daily	2
(3) Leaving aerated lagoon 3	Cell 3	Daily	2
Post treatment			
(1) Storage lagoon west	WSL	Once a week	3
(2) Storage lagoon east	ESL	Once a week	3
(3) Settling lagoon[a]		Daily	1
(4) Irrigation pump station 1[a]		Daily	2
(5) Irrigation pump station 2[a]		Daily	2
(6) Drain pump P-3 south	SD	Daily	1
(7) Drain pump P-4 north	ND	Daily	1
(8) Drain pipe samples (irrigated water, filtrate)	DT	Twice a week[c]	10-13
(9) Outlet to Mosquito Creek	SW-05	Daily	1
(10) Outlet to Big Black Creek	SW-34	Daily	1

[a] Whenever in use

[b] Five days per week

[c] Samples taken once a week during non-irrigation periods

[d] At different times each day

Table 41. WATER QUALITY PARAMETERS COMMONLY MEASURED

Physical
- (1) Solids (total solids, volatile solids, suspended solids), mg/l
- (2) pH
- (3) Temperature, °C
- (4) Conductance, µmhos/cm

Chemical
- (1) Metals: (Na, K, Ca, Mg, Fe, Mn), mg/l
- (2) Nutrients (orthophosphates, total phosphates, nitrate, nitrite, total Kjeldahl nitrogen, chloride, and sulfate), mg/l
- (3) Organics
  - Non-specific analysis
    - a. Biochemical oxygen demand (BOD), mg/l
    - b. Chemical oxygen demand (COD), mg/l
    - c. Total organic carbon (TOC), mg/l
  - Gases: Dissolved oxygen, mg/l
  - Disinfection
    - a. Residual oxygen, mg/l
    - b. Bacteria: Total coliform, fecal coliform, fecal streptococcus, (colonies/100ml) or most probable number (MPN)

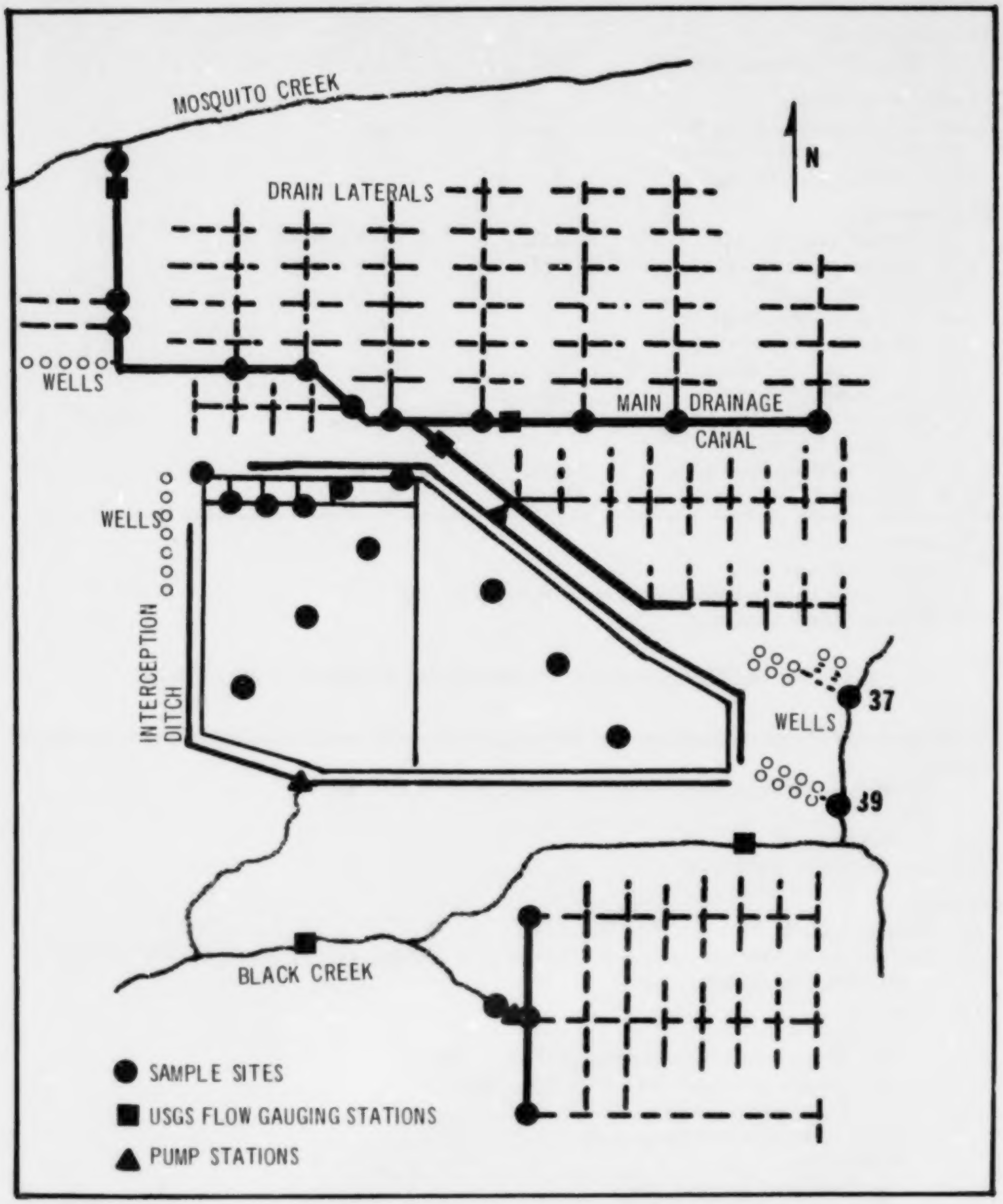


Figure 46. Locations of water sampling sites

Containers for sample collection were of three types. Samples which could be stored in plastic without contamination of the material by the container were collected in plastic jugs. Bacterial samples were collected aseptically in sterile sampling bottles, and other samples were collected in glass BOD bottles. Samples were returned immediately after collection either to the lab for immediate determination or to a refrigerator at 4 ° C for preservation.

Analytical Procedures at the WMS Laboratory

1. Physical parameters
   - a. Solids – according to *Standard Methods* (13th Edition, Sec. 148 & 224)
     Total solids – evaporation
     Total volatile solids – combustion at 550 ° C
     Suspended solids – glass fiber filtration
     Results reported in milligrams per liter, (mg/l) or (ppm)
   - b. pH – according to *Standard Methods* (13th Edition, Sec. 144 & 221); hydrogen ion selective glass electrode versus a Calomel reference electrode; results reported in standard pH units
   - c. Temperature – according to *Standard Methods* (13th Edition, Sec. 162); thermometer (mercury) of quality grade, readable to the nearest 0.2°C; results reported in degrees Centigrade
   - e. Color – according to *Standard Methods* (13th Edition, Sec. 118); visual comparison against Platinum/Cobalt standards with results reported in APHA units (American Public Health Association)
   - f. Turbidity – according to *Standard Methods* (13th Edition, Sec. 163A); by direct measurement on a Hach Model 2100A Turbidimeter, as recommended in *Methods for Chemical Analysis of Water and Waste*, EPA, 1971; results reported in Formazin Turbidity Units (FTU = Jackson Turbidity Units)
2. Chemical parameters
   - a. Metals – (mg/l) or (μg/l)
     1. Alkali earth metals – Ca, Mg, Na, K; either by flame ionization photometry or atomic absorption spectroscopy
     2. Heavy metals – Fe, Mn, Al, Cr; atomic absorption spectroscopy
     3. Trace heavy metals – Cd, Cu, Pb, Zn, Ni; when sensitivity required, anodic stripping voltametry; if part per billion sensitivity was not required, atomic absorption spectroscopy
     4. Mercury – cold vapor technique with a Coleman MAS-50 Mercury Analyzer
   - b. Nutrients – (mg/l)
     1. Phosphorus, total – persulfate digestion followed by quantitation of ortho-phosphate using the automated ammonium molybdate procedure
     2. Phosphorus, ortho – automated ammonium molybdate procedure
     3. Nitrogen, total Kjeldahl – digestion followed by analysis of ammonia produced using the Bertholet reaction (see ammonia nitrogen below)
     4. Nitrogen, ammonia – Bertholet procedure: NH_4 reaction with sodium phenoxide
     5. Nitrogen, nitrite – reaction of the nitrite ion with sulfanilamide to form a diazo compound which is then coupled with N-1-naphthylethylenediamine dihydrochloride

  6. Nitrogen, nitrate – cadmium reduction followed by quantification as nitrite

c. Anions

  1. Sulfates – barium/methythymol blue colorimetric procedure
  2. Sulfides – specific ion electrode
  3. Chlorides – liberation of thiocyanate ion from mercuric thiocyanate followed by reaction with ferric ion
  4. Alkalinity – acid titration using a potentiometric end point as outlined in *Standard Methods*, (13th Edition, Sec. 102)

d. Other analysis

  1. Arsenic – differential pulse polarography
  2. Cyanide – as in *Standard Methods*, (13th Edition, Sec. 207 B), titration of alkaline distillate with silver nitrate
  3. Boron – as in *Standard Methods*, (13th Edition, Sec. 107 A), curcumin colorimetric procedure

e. Organics, non-specific

  1. Biochemical oxygen demand (5-day) – as in *Standard Methods*., (13th Edition, Sec. 219)
  2. Chemical oxygen demand – as in *Standard Methods*, (13th Edition, Sec. 220)
  3. Total organic carbon – determined with a Beckman Model 915 Total Carbon Analyzer

f. Organics, specific

  1. Phenols – gas chromatography
  2. Pesticides, herbicides – gas chromatographic techniques

g. Gases

  1. Dissolved oxygen – as in *Standard Methods*, (13th Edition, Sec. 218B and 218F); either the Winkler method or direct reading membrane probe standardized against the Winkler method; both polarographic and galvanic probes and meters available

h. Disinfection and Bacteriology

  1. Residual chlorine – as outlined in *Standard Methods*, (13th Edition, Sec. 204A); phenylarsine oxide titration with an amperometric endpoint
  2. Bacteria – analysis for total and fecal coliform, fecal strep and Salmonella as outlined in *Standard Methods*, (13th Edition) for both membrane filter (MF) and multiple tube fermentation/most probable number (MPN) technique; sampling and identification of amoeba (in particular, *Naegleria*) done according to *Standard Methods*, (13th Edition, Sec. 606A)

i. Limnology – Plankton, the plankton net technique

Quality Control

Several in-house policies of quality control were instituted in 1973. Samples encompassing both low and high levels of pollutants were duplicated and spiked at regular intervals. Blind sample duplication also was used as a control measure, and reference samples made available from the EPA were utilized.

Some samples were split for analysis at our laboratory and at the Michigan Resources Commission Laboratory, Lansing, Michigan. Table 42 shows a comparison of results obtained on four such split samples. The correspondence in results was generally good. The WMS laboratory showed consistently higher values for total phosphorus, but the Water Resources Laboratory has noticed this discrepancy between their results and those of other labs and is checking its procedure. The findings for total chromium varied among the sampling sites, but this was probably because of known iron concentrations at two locations. Iron, if not suppressed, exhibits a positive interference in the atomic absorption spectrophotometry (AAS) of chromium. Efforts are under way to establish additional inter-laboratory quality control programs between similarly equipped labs in western Michigan.

RESULTS

Statistical Presentation

Most of the results are graphed by monthly mean with a range enclosing 90 percent of the values. The various significant parameters also have seasonal data plotted on normal probability paper so the distribution of results may be observed. The probability graphs are in Applendix C.

The data in this section are presented in the following sequence:

a. Influent
b. Biological treatment
c. Storage lagoons
d. Chlorination
e. Drain tiles
f. Discharge outfalls

Influent

The average BOD_5 in mg/l for 1973 was 175, for 1974 was 200 and for 1975 was 220, indicating that as more users joined the system BOD_5 loading increased. The gradual increase in BOD_5 since startup of operations is not so clearly evident in Figure 47 as is the seasonal response: increasing in winter, decreasing in summer. In Appendix C, Figures 1-4 show BOD_5 concentrations for selected months of high and low load conditions for two consecutive years plotted on normal probability paper. Also in Appendix C is the plot of influent flow with BOD_5 loading for three years in Figure 5 and the plot of the BOD/COD ratio for influent in Figure 6.

Suspended solids concentration in influent is depicted in Figure 48 and shows a gradual decrease from 300 mg/l in 1973 to 259 mg/l in 1975. This decrease was attributed partially to an increase in rate of flow. There seems to be no seasonal pattern to the fluctuations in concentration, and the average levels compare favorably with those for most domestic treatment systems. Figure 7 in Appendix C depicts monthly average suspended solids in kilograms and ppm.

Figure 49 depicts 1975 monthly average concentrations of ammonia nitrogen, total Kjeldahl nitrogen (TKN), and ortho-phosphate in the raw wastewater received during 1975. There was a general decrease in both phosphorus and nitrogen. In early 1975 the TKN levels dropped from 14 ppm to approximately 4 ppm and ammonia nitrogen, correspondingly, dropped from 13 ppm to 3.4 ppm. The drop in phosphorus from 1.7 to 0.7 mg/l occurred during a period of very high groundwater, and the overall reductions were probably due to a combination of changed patterns of industrial activities and to infiltration of groundwater into the collection system. Table 43 shows the total nutrient average monthly results for the period 1973 to 1975. The influent nitrogen con-

Table 42. COMPARISON OF THE ANALYTICAL RESULTS OBTAINED AT WMS AND THE MICHIGAN WATER RESOURCES COMMISSION LABORATORY

	Samples taken from August 26 to 27, 1975							
	Mosquito Creek outfall		Laketon Pump station		Well discharge point 39		Well discharge point 37	
Parameter, mg/l	WMS lab results (pH=7.2)	State lab results	WMS lab results (pH=6.85)	State lab results	WMS lab results (pH=7.38)	State lab results	WMS lab results (pH=7.09)	State lab results
Five-day BOD	1.60	< 5.00	0.50	< 5.00	< 0.20	< 5.00	0.80	< 5.00
Suspended solids	2.50	7.00	39.4	33.0	3.30	4.00	16.4	13.0
Total phosphorus	0.09	< 0.01	0.07	< 0.01	0.17	0.02	0.05	0.02
Nitrate nitrogen	3.78	3.30	1.80	1.70	2.59	3.20	0.29	0.35
Ammonia nitrogen	0.11	0.07	0.40	0.38	< 0.05	0.07	0.21	0.21
Nitrite nitrogen	0.12	0.11	0.03	--	0.01	0.01	0.01	0.01
Chlorides	88.5	83.0	50.0	--	16.0	18.0	10.9	14.0
Sulfide	--	< 0.50	--	--	--	--	--	--
Total iron	0.32	0.32	17.1	15.0	0.63	0.70	6.92	6.50
Total chromium	< 0.03	< 0.01	< 0.03	0.10	< 0.03	< 0.01	< 0.03	0.04

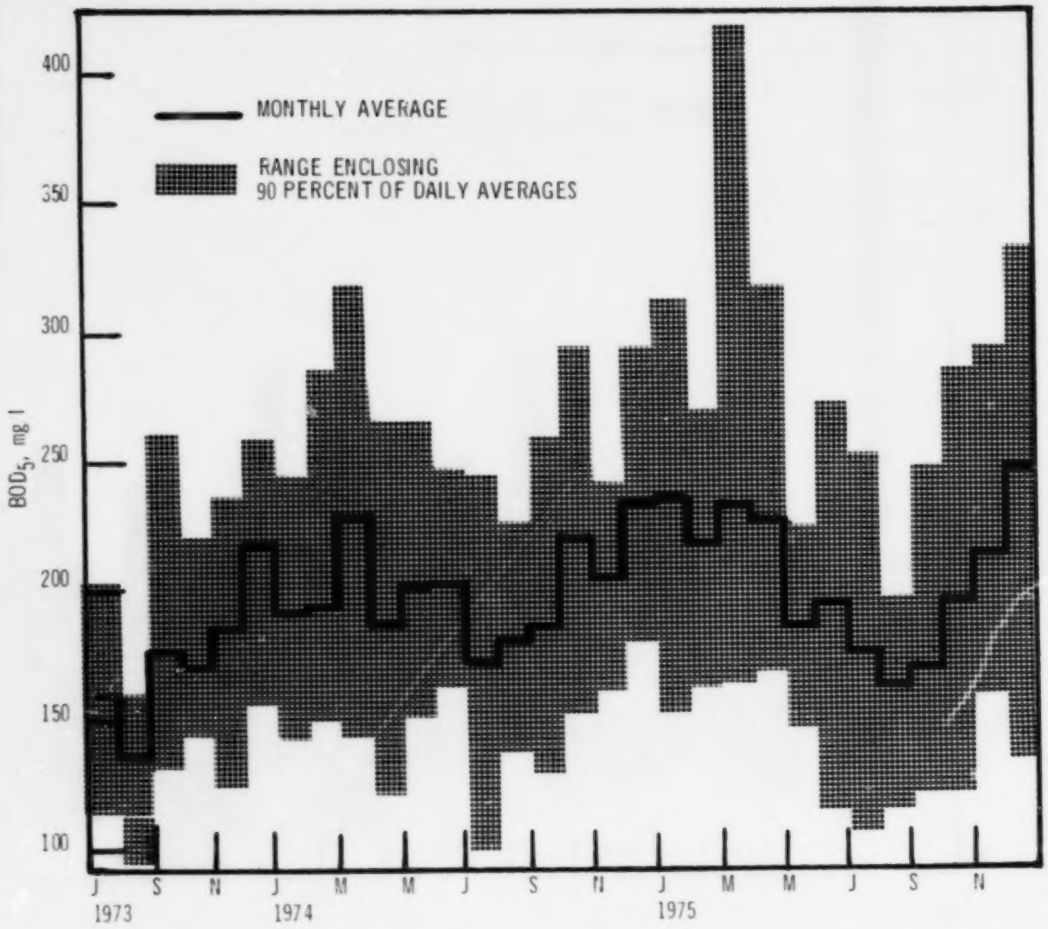


Figure 47. Biological oxygen demand in influent, 1973-1975

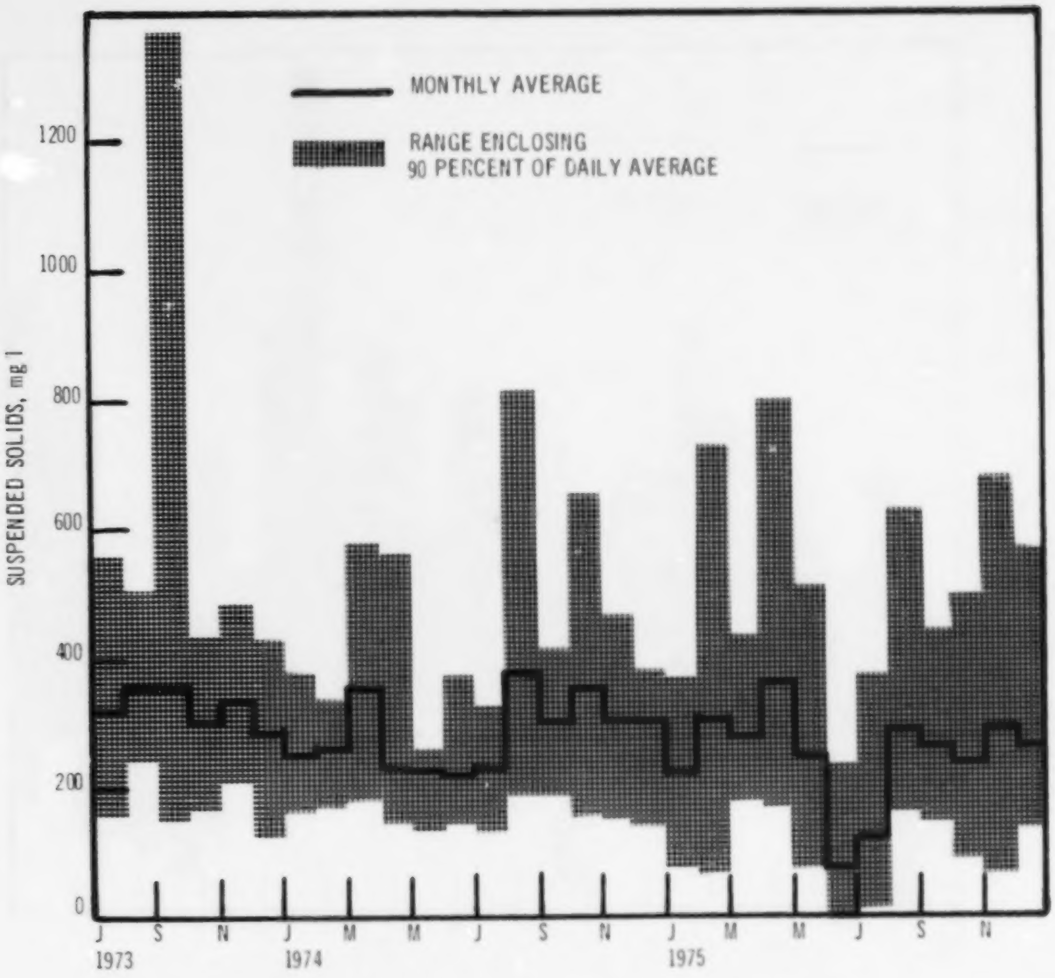


Figure 48. Suspended solids in influent, 1973-1975

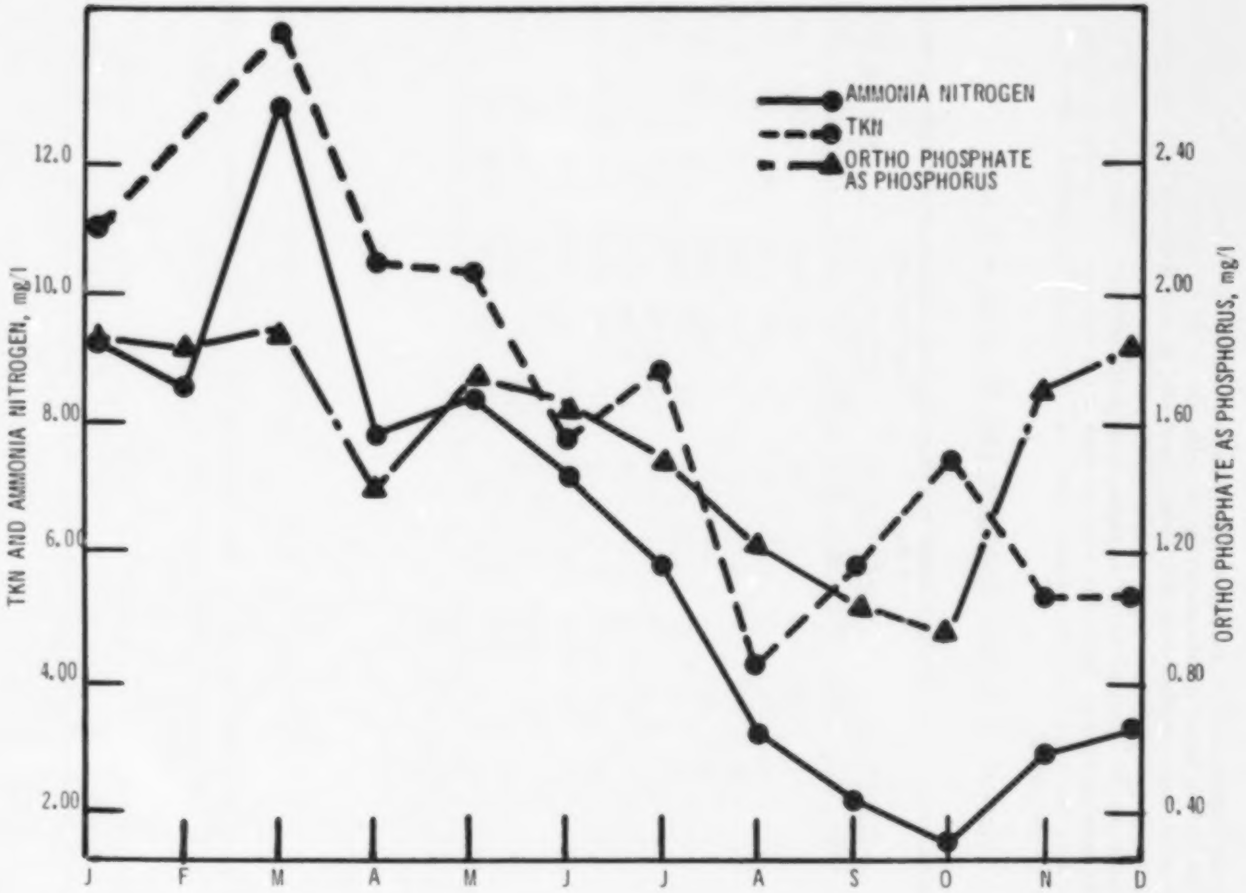


Figure 49. Ammonia nitrogen, total Kjeldahl nitrogen and ortho phosphate in influent, 1975

centrations were below expected levels for domestic wastewater. In Appendix C, Figures 8 through 15 show the normal distribution levels of the nutrients during similar periods in two consecutive years.

During July and August of 1973, a monitoring program was undertaken to determine the concentrations of the various heavy metals present in the influent. Table 44 shows the average monthly concentrations for these metals during this phase. Compared to most domestic/industrial wastewater, the heavy metals (cadmium, copper, lead, nickel, and chromium) were present in extremely low concentrations. As indicated by the averages, most metals were at or near the limit of detection of the instrumentation. Since that time, because of the very low concentrations, these metals have been monitored with less frequency, only to "spot check" for possible increases. No increases have been found.

Table 43. INFLUENT NUTRIENTS 1973 THROUGH 1975, mg/l

	Ammonia nitrogen (N)			Orthophosphate (P)			Total Kjeldahl nitrogen (N)			Total phosphorus (P)		
Month	1973[a]	1974	1975	1973[a]	1974	1975	1973[a]	1974	1975	1973[a]	1974	1975
January	–	3.95	9.20	–	1.12	1.86	–	NA	10.90	–	NA	NA
February	–	5.96	8.56	–	1.60	1.83	–	NA	NA	NA	NA	NA
March	–	4.63	12.90	–	1.52	1.89	–	NA	14.10	–	NA	2.40
April	–	7.08	7.80	–	1.88	1.41	–	NA	10.50	–	NA	2.57
May	NA[b]	9.06	8.40	NA	1.70	1.74	NA	9.56	10.39	NA	2.32	NA
June	NA	7.15	7.25	NA	1.91	1.66	NA	11.38	7.75	NA	2.77	NA
July	3.39	10.70	5.85	1.02	2.16	1.50	NA	12.00	8.88	NA	2.93	NA
August	3.33	8.30	3.27	0.91	2.15	1.23	5.19	9.60	4.31	NA	2.58	NA
September	3.87	10.96	2.27	2.61	2.33	1.05	6.65	NA	5.78	NA	NA	NA
October	3.72	9.19	1.56	1.15	2.13	0.96	6.83	NA	7.46	1.87	NA	1.68
November	3.03	8.61	2.94	0.85	2.19	1.72	6.33	NA	5.33	1.73	NA	2.12
December	4.15	9.32	3.34	1.28	1.87	1.86	6.50	NA	5.37	2.08	NA	2.51

[a] Wastewater first received in May, 1973

[b] NA = not analyzed

Table 44. INFLUENT HEAVY METALS, mg/l

Year/month	Cadmium	Copper	Lead	Nickel	Chromium
1973					
February	0.009	0.03	0.05	0.04	0.03
August	0.030	0.02	0.11	0.06	0.05

Biological Treatment Cells

Under current flow conditions of 98.8 to 106.4 TCMD the average retention time in each cell is approximately 36 hours. Table 26 shows the mode of operation of the three aeration cells from 1973 through 1975. Each cell in full operation expended approximately 600,000 KWH per month.

In Figures 50 and 51 the 1974-1975 rates of BOD removal are correlated with rates of KWH consumption. During 1974, the average KWH consumption was one million KWH for an average BOD removal of 0.48 million kg/month. In February, 1975, the mode of operation of the cells was switched to two cells in series with the number of aerators reduced so that power requirements were cut in half. Thus, in 1975, the average power requirements were 0.55 million KWH for an average BOD removal of 0.43 million kg/month, indicating that it was possible to reduce power requirements by nearly half without sacrificing much BOD removal. Significant cost-saving was realized.

In Figure 50 the "double" KWH consumption of 1974 resulted in the removal of 45,500 extra kg of BOD, which when expressed in terms of load on the storage lagoons amounted to 2.5 kg/ha. This is negligible. Two-cell operation at 100 percent capacity was clearly a less efficient mode.

Other variables which affected BOD removal were: seasonal variations in removal due to dissolution of atmospheric oxygen in lagoon water as a function of ambient temperature; seasonal variations in influent profiles, as discussed in the previous section.

In Figure 51, BOD removal is expressed per KWH. Comparison of the three-cell mode of operation of 1973 and the single-cell mode in 1975 revealed a three-fold difference in efficiency: from 0.75 kg/KWH to 0.23 kg/KWH. Similar comparison of one-cell and two-cell modes indicated a two-fold difference in efficiency: 0.75 kg/KWH to 0.45 kg/KWH.

Figure 52 depicts the overall BOD_5 concentrations leaving the treatment cells with the solid line as the monthly mean and the shaded area encompassing 90 percent of the daily averages. Fluctuations in the discharge concentrations were attributed mainly to operational changes made in the operation of the treatment cells. The overall BOD_5 concentration going to storage was approximately 75 mg/l.

Figure 53 illustrates the suspended solids concentrations leaving the biological treatment cells, using the same presentation format as for Figure 52. Suspended solids were reduced from an average of 300 mg/l in the influent to 150 mg/l in the aeration cells, the decrease attributed to deposition of sludge in the floor of the treatment cells. This is confirmed with a comparison of the monthly averages for influent and effluent in Figure 53; the difference represents sludge deposition.

In October-November, 1974, the disparity between the total suspended solids in influent and in effluent was due to a change in the mode of operation. Cells one and two were in full operation while flow was going into cell three without mixers or aerators operative. Therefore, settling in cell three was pronounced, and measurements from cell three gave lowered suspended solids readings.

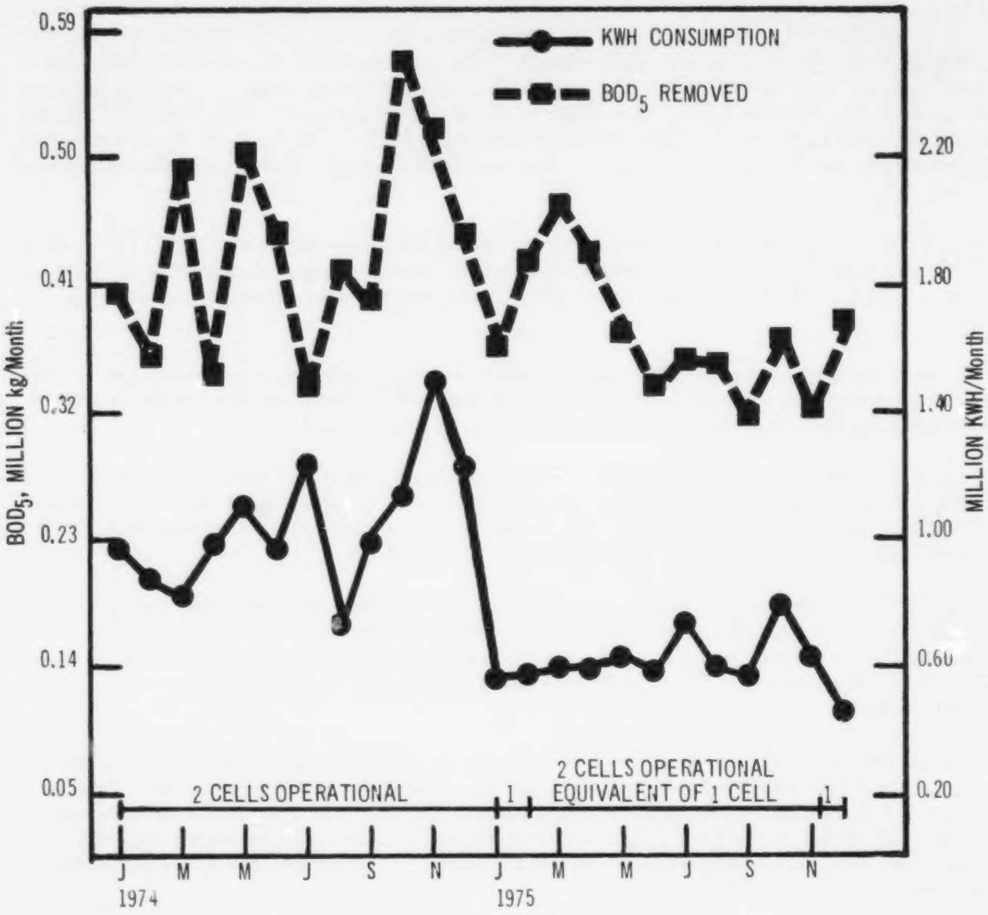


Figure 50. Five-day biochemical oxygen demand removal and KWH consumption in the biological treatment cells, 1974 & 1975

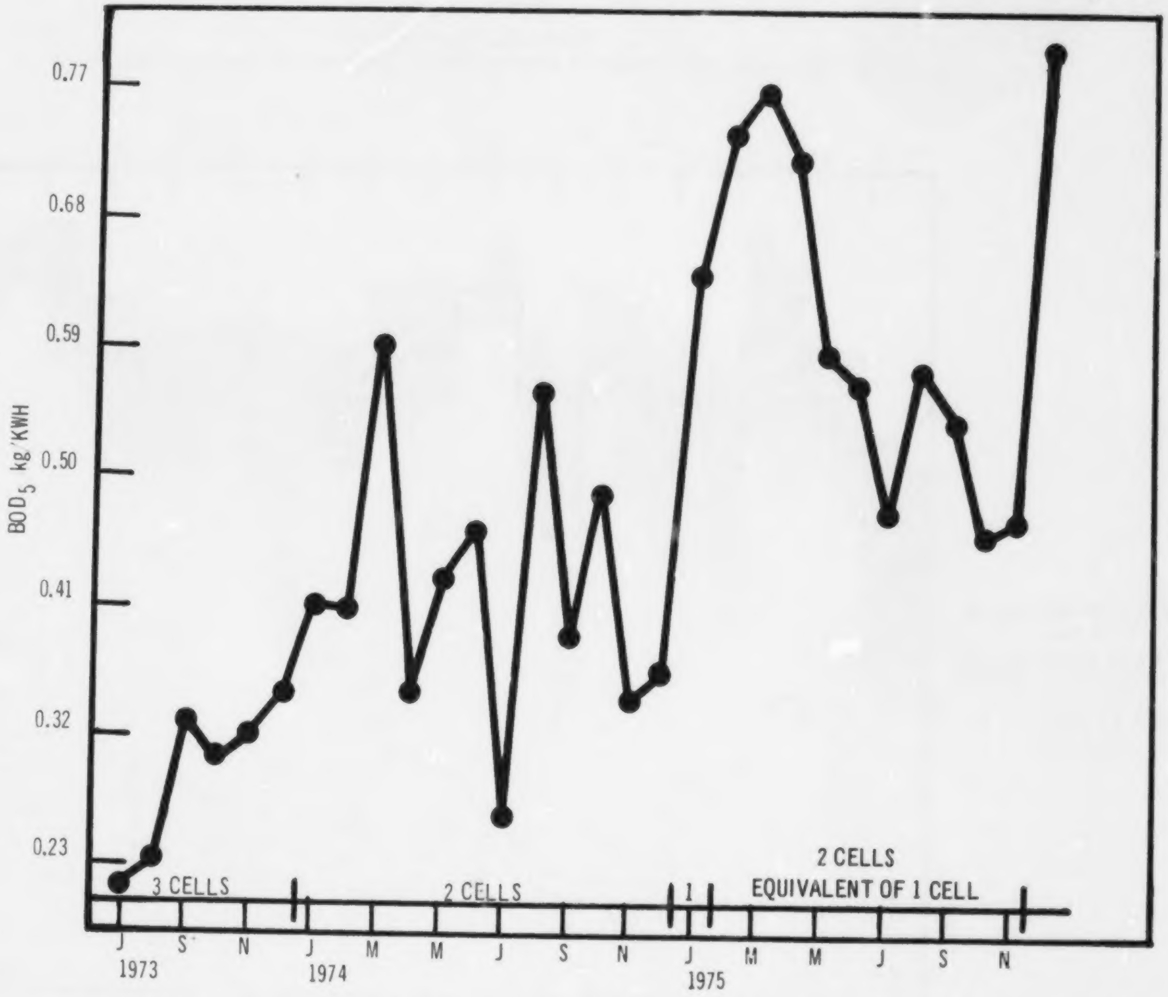


Figure 51. Five-day biochemical oxygen demand removal per KWH in biological treatment, 1973-1975

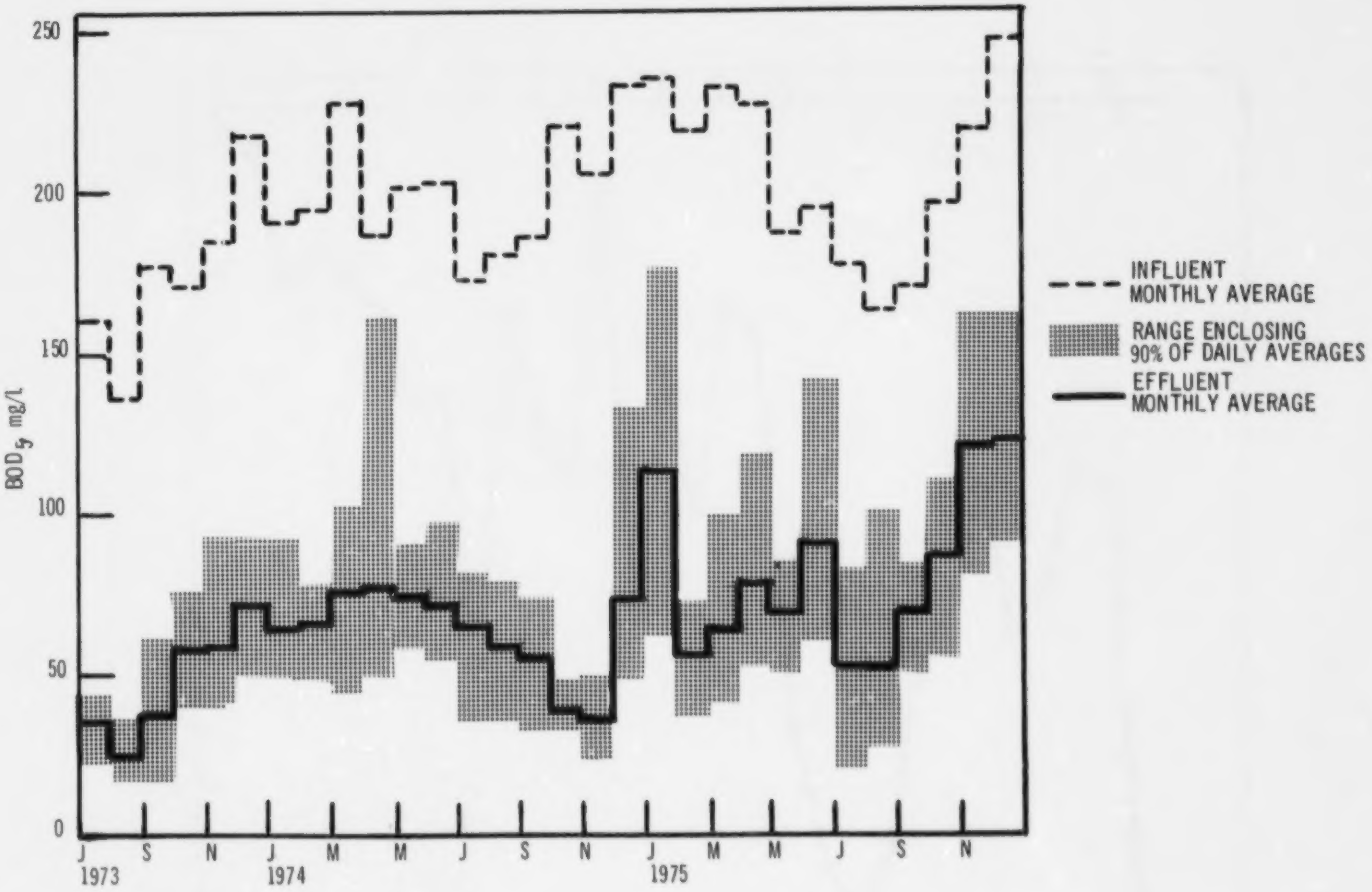


Figure 52. Five-day biochemical oxygen demand in effluent from the biological treatment cells, 1973-1975

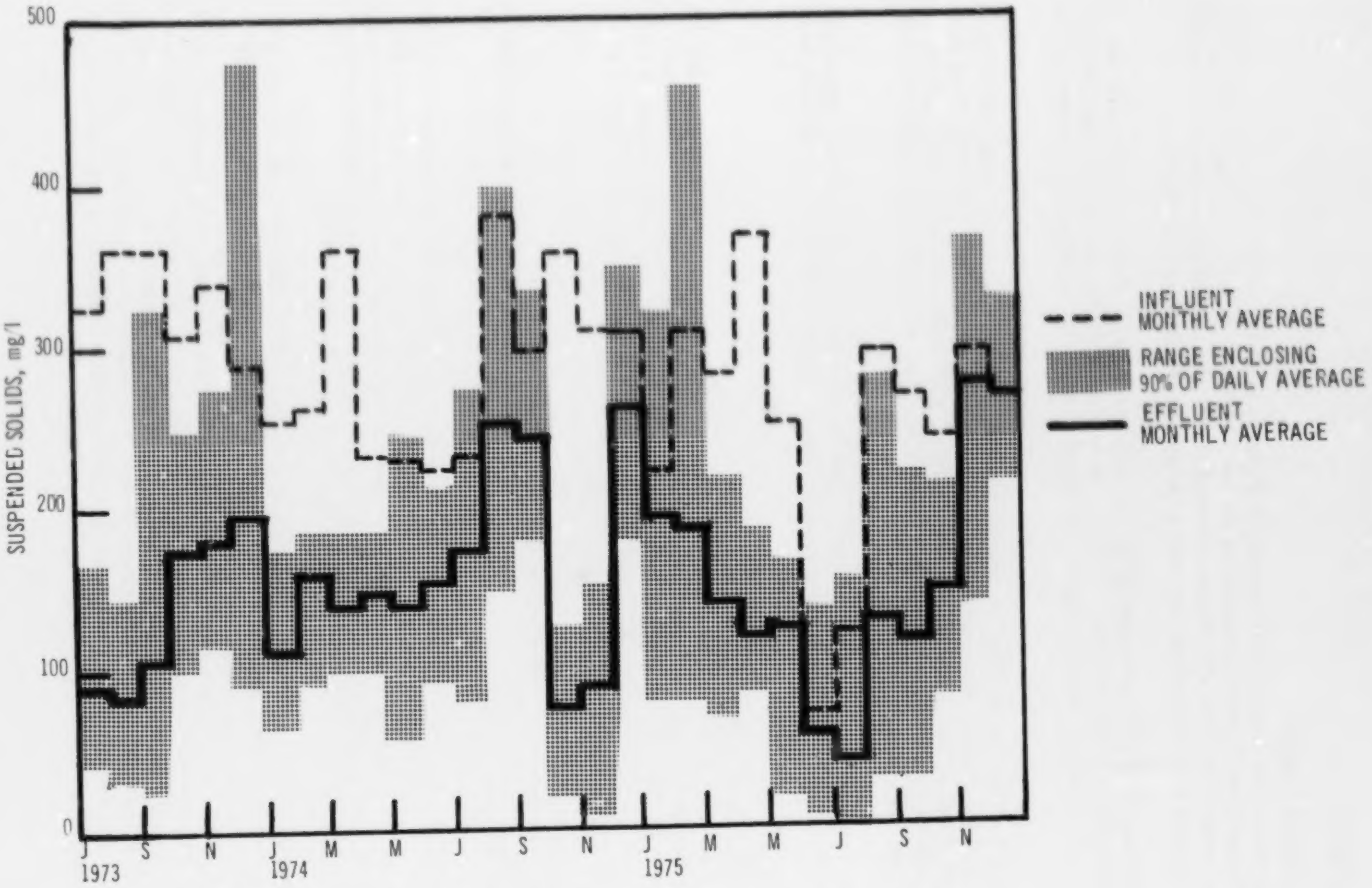


Figure 53. Suspended solids in effluent from biological treatment cells, 1973-1975

Storage Lagoons

BOD_5 in Storage Lagoons–

Figure 54 shows the lagoon levels versus BOD_5 and suspended solids for the east storage lagoon. The BOD results are monthly averages for the period 1973-1975, and the suspended solids are monthly averages for 1974-1975. It was assumed that in the case of most – if not all – parameters, the west storage lagoon parallels the east, so separate analyses were not included.

The general trend for storage lagoon BOD_5 was to decrease with duration of impoundment. As the lagoon was refilled, BOD increased. This may be explained by the excellent oxygen transfer capacity of the relatively shallow lagoons, achieving waste stabilization and concomitant lower BOD.

The seasonal variations in BOD_5 concentration in the lagoons ranged from a high of about 27 mg/l to a low of about 5 mg/l. Although Bauer Engineering design specified that BOD_5 loading should not exceed 22 kg/ha/day, and although the combination of large surface area and shallow depth of these lagoons is acknowledged to be efficient at BOD_5 removal, the load limit of BOD for this system is not yet known.

Biological oxygen demand should be explored both for reasons of clarifying future operational conditions of this project and for establishing a functional kinetic model of use to all such treatment systems.

Suspended Solids in Lagoons –

As the lagoon level decreased, the concentration of suspended solids increased, probably due to the action of waves disturbing bottom solids as the water grew more shallow. The converse was also found to be true: as the level of the water in the lagoon rose, the concentration of suspended solids decreased. The maximum-minimum range over 1974-1975 was from about 50 mg/l to about 5 mg/l, and the average was 25 mg/l.

Ammonia-N, Nitrate-N, and Ortho-Phosphate in East Lagoon –

The 1973-1975 monthly averages of concentrations of these chemical parameters in the east lagoon are plotted in Figure 55, along with the corresponding lagoon water level.

Ammonia-nitrogen concentration rose with water level. The effluent from the biological treatment cells was high in ammonia nitrogen, so as the lagoon was filled, the concentration went up. During periods of sustained impoundment, the ammonia in the lagoon water was oxidized to nitrate. So throughout irrigation, the ammonia nitrogen remained low and began increasing again as the lagoon was refilled. The same pattern was observed in the west lagoon.

Although the oxidation of ammonia to nitrate was not quantitative, there seemed to be an indirect correlation between lagoon water level and nitrate concentration. When the east lagoon was filled in the spring of 1975, the ammonia nitrogen peaked at over 6 mg/l. During the next three months of impoundment, the ammonia nitrogen decreased to less than 0.5 mg/l. Simultaneously, the increase in nitrate nitrogen went from almost zero to only 4 mg/l. The nitrogen shortfall remains difficult to explain, for the pH of the lagoons remained stable at about 7.5, obviating any substantial loss of ammonia to the atmosphere. Possible explanations might include a combination of denitrification activity and algae uptake, but further work is indicated in nitrogen cycles to better understand nitrogen dynamics during impoundment.

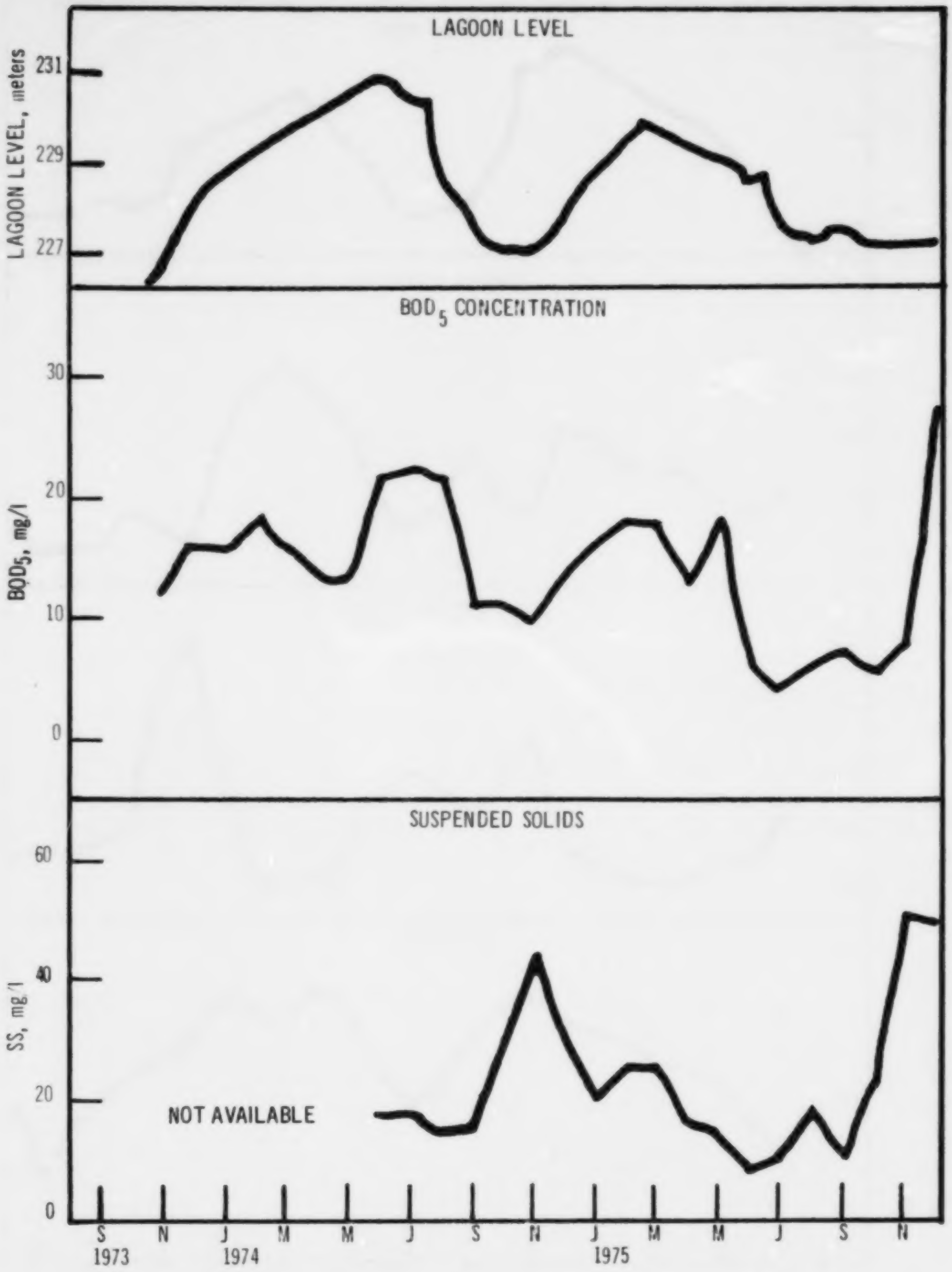


Figure 54. Water level, five-day biochemical oxygen demand concentration, and suspended solids in east storage lagoon, 1973-1975

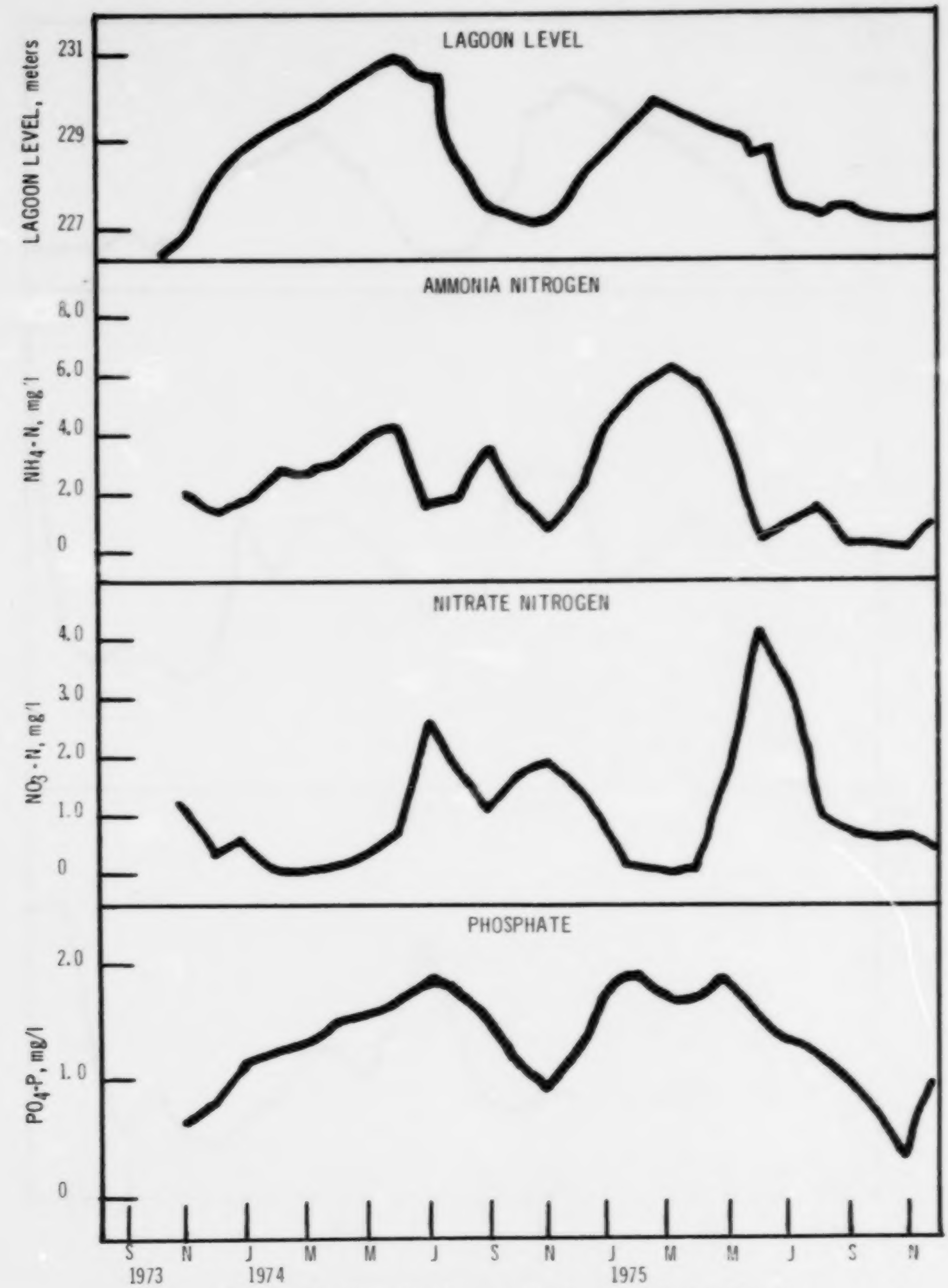


Figure 55. Water level, ammonia nitrogen, nitrate nitrogen, and phosphate in east storage lagoon, 1973-1975

In the east lagoon, phosphorus ranged from 0.6 to 1.8 mg/l from 1973 to 1975. The concentration of phosphorus roughly paralleled ammonia nitrogen in that concentration increased during lagoon filling and decreased during impoundment. The decline in concentration during long storage was attributed to either biological activity involving phosphorus complexation or to mineralization, or to both. Further research is required for definitive answers.

Table 45 contains the yearly average concentrations of metals and anions with ranges for the influent and the two storage lagoons. In late 1973, the filling of the east storage lagoon was begun, and the data obtained from the analyses over those three months are not necessarily typical of lagoon findings. During 1974 there was pumping of water from the interception ditches back into the lagoons; thus the levels of alkali earth metals in the lagoons were lower, with the exception of magnesium which was higher because groundwater magnesium concentration was higher than in lagoon water. Although in 1975 the volume of pumping from interception ditch-to-lagoon was reduced, the elevated magnesium in the lagoon persisted to some extent. In the influent, the heavy metals concentrations were very low. Among the trace heavy metals, zinc ranged from below detectable limits to 15 mg/l; the three-year average concentration was less than 0.7 mg/l. Other trace heavy metals, such as copper, cadmium, chromium, nickel, lead and mercury, were below 50 ppb. In the storage lagoons, heavy metal concentrations were further reduced to levels considered less than significant.

The chlorides increased in the influent from an average of 154 mg/l in 1973 to 182 mg/l in 1975. Whereas sulfate ion concentration showed no significant change in the influent, averaging approximately 80 mg/l, in the east storage lagoon it increased to 100 ppm. This increase was due to conversion of reduced sulfur species to a higher oxidation state. In the west lagoon the sulfate increase was not observed, probably due to the dilution factor introduced by the water volume in interception ditches. The same dilution was also apparent in chloride ion concentration in the west lagoon, whereas chloride remained relatively unchanged in the east storage lagoon.

Appendix C contains figures which show the 90 percent range and monthly means for these sample points and these parameters. See Figures 16 through 25, Appendix C.

Table 46 lists the bacteriological data during a four-month isolation period in the east storage lagoon from March through June, 1975.

Table 46. EFFECT OF IMPOUNDMENT ON FECAL COLIFORM ORGANISMS

Date	East storage fecal coliform, colonies/100 ml
March, 1975	5.0×10^3
April, 1975	1.3×10^2
May, 1975	1.0×10^2
June, 1975	1.1×10^2

These values were generated from four log-probability plots of daily data obtained during this four-month period. See Appendix C, Figures 26-29.

Table 45. COMPARISONS OF CONCENTRATIONS OF METALS AND ANIONS IN INFLUENT AND STORAGE LAGOONS, 1973, 1974 AND 1975

	Influent [Biological treatment cells][a]		East storage lagoon		West storage lagoon	
Parameter/ year	Avg, mg/l	Range, mg/l	Avg, mg/l	Range, mg/l	Avg, mg/l	Range, mg/l
Ca						
1973	46.3	23.2 → 120	70.6	63.1 → 77.4	52.7	30.6 → 68.7
1974	73.3	31.0 → 286	61.9	43.0 → 84.0	51.7	28.0 → 59.0
1975	73.6	48.3 → 142	60.3	52.9 → 78.0	56.3	46.9 → 66.4
Mg						
1973	26.9	0 → 92.2	13.6	10.9 → 18.9	26.3	12.4 → 73.8
1974	16.0	11.0 → 23.8	15.5	14.4 → 18.6	17.4	14.3 → 19.1
1975	14.3	10.5 → 20.3	15.8	13.5 → 21.3	16.2	13.3 → 21.0
Na						
1973	160	55.7 → 1253	152	140 → 162	124	87.1 → 166
1974	157	68.0 → 377	146	130 → 161	91.2	73.0 → 121
1975	166	68.9 → 1010	164	144 → 187	125	81.2 → 177
K						
1973	11.6	4.20 → 116	12.7	8.90 → 15.7	9.20	6.10 → 14.0
1974	11.6	1.00 → 88.5	11.4	9.20 → 13.8	5.60	3.80 → 6.70
1975	10.5	5.90 → 33.6	9.80	8.90 → 11.0	7.50	5.60 → 18.5
Fe						
1973	0.90	0 → 3.40	1.20	0.80 → 2.00	0.90	0 → 1.90
1974	1.00	0.40 → 10.5	1.00	0.60 → 1.70	0.60	0.30 → 1.40
1975	0.80	0.30 → 5.00	1.20	0.90 → 1.50	0.90	0.30 → 3.10
Mn						
1973	0.30	0 → 2.90	0.20	0.10 → 0.30	0.10	0 → 0.30
1974	0.30	0.10 → 2.30	0.20	0 → 0.30	0.10	0 → 0.30
1975	0.30	0.10 → 1.00	0.20	0.20 → 0.30	0.10	0 → 0.20
Zn						
1973	0.60	0 → 6.80	0.30	0.10 → 2.30	0.20	0.10 → 0.50
1974	0.80	0 → 15.1	0.20	0.10 → 0.30	0.10	0 → 0.20
1975	0.60	0 → 3.90	0.10	0.10 → 0.20	0.10	0 → 0.20
SO_4						
1973	80.0	33.0 → 312	101	52.0 → 368	84.0	53.0 → 146
1974	82.0	19.0 → 710	97.0	43.0 → 670	74.0	23.0 → 270
1975	75.0	8.00 → 300	101	33.0 → 1030	78.0	23.0 → 198
Cl						
1973	154	64.0 → 297	189	143 → 367	133	49.0 → 230
1974	176	77.0 → 384	161	92.0 → 218	103	45.0 → 135
1975	182	45.0 → 366	169	62.0 → 217	138	51.0 → 184

[a] The values for these parameters in the biological treatment cell showed no significant change from the influent values. For itemized data, see Appendix C, Table 2.

After only two months of isolation, the fecal coliform count was stabilized at about 100 colonies per 100 ml, excelling the standard of 200 colonies/100 ml. Such die-off on a regular basis could provide a cost savings through a substantial reduction in chlorine usage, but an opportunity to repeat this experiment was not afforded because the operational modes of the storage lagoons did not allow for a period of four months isolation. Again, further investigation is recommended.

Chlorination

Water for irrigation was drawn either from the storage lagoons exclusively, or from the storage lagoon and from the settling lagoon which contained water from the biological treatment cells. In the case of the impounded water, chlorination was not required for irrigation because natural die-off reduced the number of indicator organisms to below State of Michigan discharge specifications.* But irrigation water from the outlet lagoon did require chlorination.

Table 47 lists residual chlorine levels and degree of disinfection for the north and south irrigation ditches for 1975. The initial dosage of 9 mg/l chlorine resulted in excessive residual chlorine, 2 to 4mg/l. When the dosage was dropped to 7 mg/l, poor disinfection resulted, regardless of residual chlorine levels. The failure was attributed to either incomplete mixing in the ditches or to insufficient residual time while under a maximum irrigation flow rate. Because the BOD concentration was low at 20 to 30 mg/l, it was believed that the low level of organics would have little effect on the disinfection process. As to whether coliform decrease was an indicator of disinfection, the question is currently considered to be unresolved.

Drainage Pipes

Most of the irrigated farmland has a subsurface system of drain pipes. Figures 15 and 16 illustrate the layout of the system and the relationship of the irrigation circles to the drain pipes. The pipe system is numbered according to the last circle drained into the discharge canal; *e.g.*, drain pipe 19 drains circles 19 through 22.

For the purposes of this discussion, data from "typical" drain pipes were selected. Pipe numbers 11, 19, 34, and 48 were chosen on the basis of the type of soil drained. Number 11, collecting leachate from circles 9, 10, and 11, drains Rubicon soils. Number 19 drains basically Au Gres soil. Drain pipe 34 services circles 31A, 32, 33, and 34 and represents a mixture of Au Gres, Granby, and Roscommon soils. Number 48 drains an area almost exclusively of Roscommon soils.

Drain pipe data for the period of 12/74 through 11/75 are presented in bar graphs which show total rainfall, average centimeters irrigation, and the two combined, or the total hydraulic loading. Included in the same figures are the average monthly concentrations of nitrate nitrogen and chloride and the timespan of fertigation.

Au Gres Series – Drain Pipe 19 –

Figure 56 depicts the results from the drain pipe 19 leachate. From December, 1974, through March, 1975, a period which included the 1974 post-irrigation season and the 1975 pre-irrigation season, the nitrate nitrogen in the leachate averaged about 2 mg/l. From April, 1975, when irrigation resumed, through August, nitrate nitrogen in the leachate sharply increased, going from 2 mg/l during pre-irrigation to 4.3 mg/l during irrigation. The concentration peaked in July-August, the period of maximum hydraulic loading and maximum nitrogen application via fertigation and irrigation.

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* For the permissible levels of BOD_5, SS and the total P according to NPDES guidelines, see Table 52.

Table 47. POST-CHLORINATION COLIFORM IN UNIMPOUNDED IRRIGATION WATER, 1975

	North pumping station		South pumping station	
Date	Residual Cl_2, ppm	Post-chlorination[a] total coliform, MPN[b]	Residual Cl_2, ppm	Post-chlorination[a] total coliform, MPN[b]
6/27	1.29		0.32	
6/30	0.17	4.6×10^2	ND[c]	1.7×10^2
7/ 1	0.29	2.4×10^4	ND	1.6×10^4
7/ 2	1.57	5.4×10^3	0.15	3.3×10^2
7/ 3	3.01	1.6×10^4	0.80	1.3×10^3
7/ 8	2.72	1.6×10^4	0.05	3.5×10^3
7/ 9	4.02	2.4×10^3	1.84	1.1×10^3
7/10	3.88	1.6×10^4	2.19	9.2×10^3
7/11	3.21	9.2×10^3	ND	1.6×10^4
7/14	ND[c]	$\geq 2.4\times10^4$	ND	$\geq 2.4\times10^4$
7/15	1.77		ND	
7/16	ND	1.7×10^3	ND	1.6×10^4
7/17	ND	$\geq 2.4\times10^4$	ND	$\geq 2.4\times10^4$
7/18	0.97		ND	
8/ 6	ND	$\geq 2.4\times10^4$	ND	$\geq 2.4\times10^4$
8/ 7	ND	$\geq 2.4\times10^4$	ND	$\geq 2.4\times10^4$
8/ 8	ND	5.4×10^3	ND	$\geq 2.4\times10^4$
8/11	1.13	$\geq 2.4\times10^4$	ND	1.6×10^4
8/12	0.91	3.5×10^3	ND	$\geq 2.4\times10^4$
8/13	0.92	4.9×10^2	0.11	$\geq 2.4\times10^4$
8/14	0.51	$\geq 2.4\times10^4$	ND	$< 2.0\times10^1$
8/15	2.43	4.9×10^2	0.91	3.3×10^2
8/18	3.13	1.1×10^3	0.73	9.2×10^3
8/21	2.57	5.4×10^3	0.19	$\geq 2.4\times10^4$
8/22	3.61	1.1×10^3	ND	$\geq 2.4\times10^4$
8/29	3.12	2.4×10^3	0.01	$\geq 2.4\times10^4$

[a] Coliform count in influent was in excess of 1×10^6 and was regarded as too numerous to count.

[b] Most Probable Number

[c] Not detectable (below detection limits)

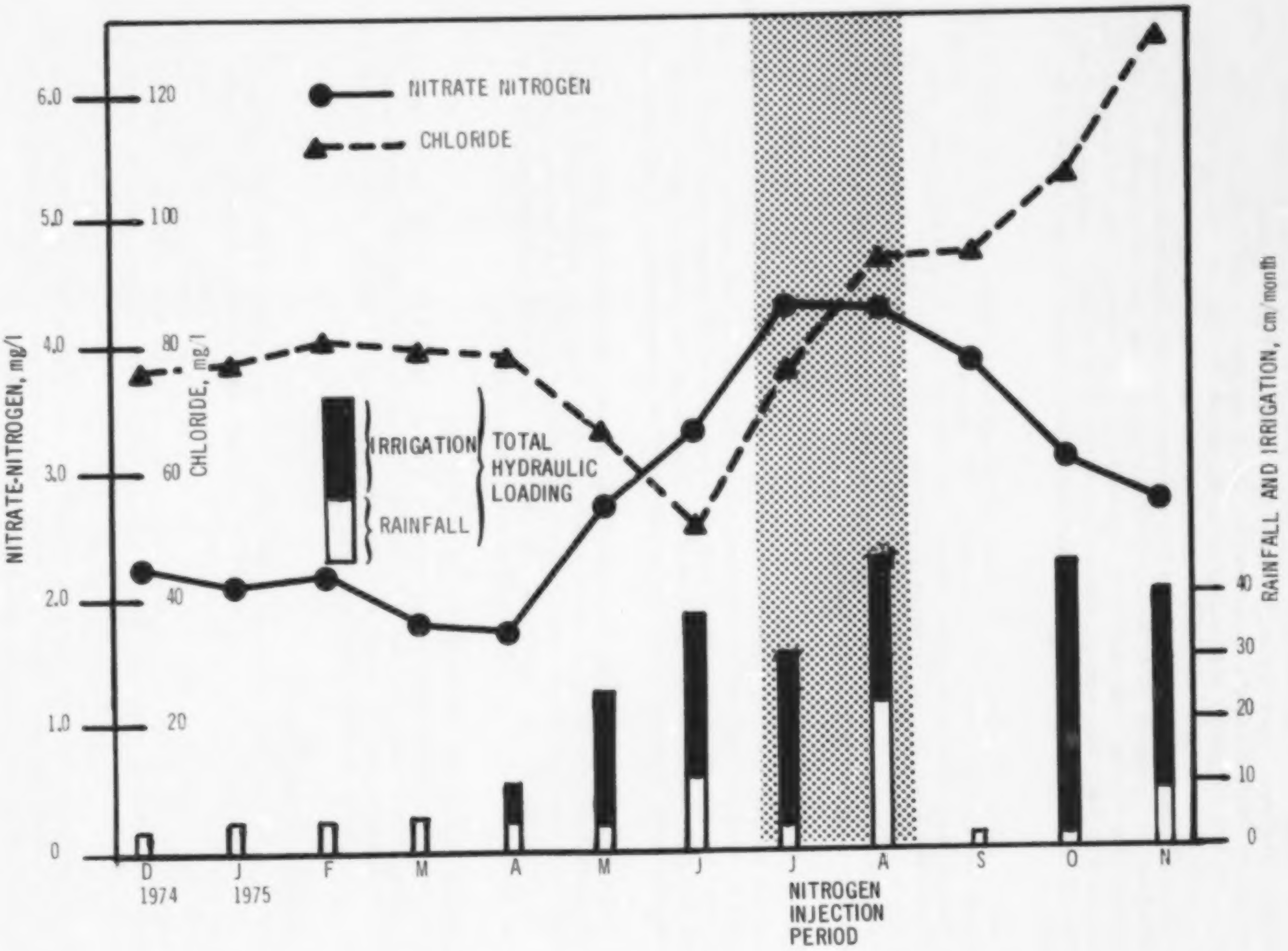

Figure 56. Nitrate, chloride and total precipitation for drain pipe 19 effluent, 1975

During the period September-November when nitrate dropped to 2.7 mg/l, the decrease was attributed to two factors: (1) termination of nitrogen fertigation, and (2) the decreased rate of oxidation of ammonia to nitrate during the cooler weather. But it was also concluded that, for several reasons, the nitrogen picture was incomplete for the period of 1974-1975. The stover was not disced under until the spring of 1975 because of the prolongation of harvest into early December, thus atypically removing organic nitrogen from the equation. And, besides the fact that there was no significant fertigation in 1974, the overall 1974 irrigation year was not representative of typical operations. The system lends itself to the successful study of nitrogen plant-soil-leachate dynamics, but dependable data were not obtained due to this whole series of obfuscatory hurdles. Figures 30 through 34 of Appendix C contain statistical variations for nitrate nitrogen for this period.

The data for chloride leachate from Au Gres soils are graphed in Figure 56 and show that the concentration was stable at 80 mg/l from December, 1974, through March, 1975. From early spring thaw through June, chloride dropped to 50 mg/l, and with the resumption of irrigation it again sharply increased, reaching in November the maximum of about 130 mg/l. The interruption of irrigation in September to allow corn to mature was not reflected in drain pipe chloride, but the data in Figure 56 indicate that, for both nitrogen and chloride, the concentrations in Au Gres leachate were in direct response to hydraulic loading.

Roscommon Series – Drain Pipe 48 –

Roscommon leachate data from drain pipe 48 are graphed in Figure 57. Pre-irrigation concentrations of nitrate nitrogen at 1 mg/l and of chloride at 32 mg/l were stable, and, with the onset of irrigation, both changed: nitrate peaking at 2.5 mg/l in June, a two-fold increase, and chloride dropping to 24 mg/l. Throughout the remainder of the irrigation period, nitrate gradually fell and chloride increased. Interruption of irrigation was reflected in some lowering of both parameters.

The circles serviced by drain pipe 48 received less irrigation than those serviced by 19, and overall concentrations of nitrogen and chloride were lower. This is an indication that in Roscommon soil types there is a direct correlation between hydraulic loading and the concentrations of such mobile ions as chloride and nitrate. But the similarity of trends suggested that the Roscommon and Au Gres soil types share similar percolation properties.

Roscommon, Au Gres and Granby Series – Drain Pipe 34 –

The data from the leachate representing a mixture of Roscommon, Au Gres and Granby soils serviced by drain pipe 34 are presented in Figure 58. Though this area received more irrigation than the Roscommon area, the strong similarity between Figure 57 and 58 indicates the two areas behave much alike in drainage characteristics.

Rubicon Series – Drain Pipe 11 –

Leachate from Rubicon series serviced by drain pipe 11 is presented in Figure 59, and again, there are remarkable parallels in concentrations of nitrate and chloride in response to similar hydraulic loading. The data for August-September were predicted values: a bottleneck in the discharge canal created extremely high water and made dependable sampling impossible. Unlike the leachate from the Au Gres series, this drainage showed an increase in nitrogen during the final month of irrigation, going from 2.5 to 4.5 mg/l. The reason for the increase is not known, and an effort to identify the cause is being made.

Table 48 summarizes the average nitrate nitrogen data from the four drain pipes for the period of June, 1974, through November, 1975. The reason data are not included for the months previous to June, 1974, is that the irrigation rigs were not yet operational.

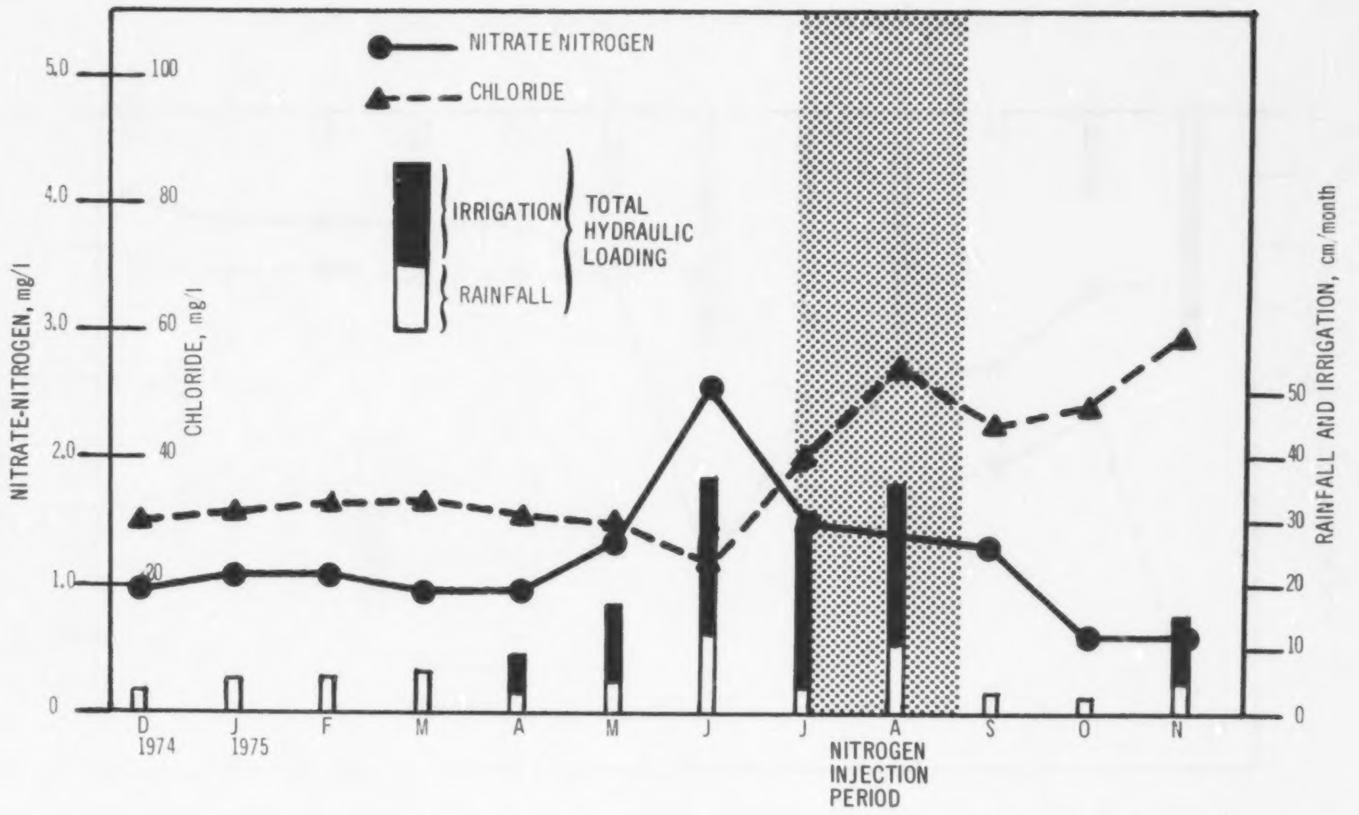

Figure 57. Nitrate, chloride and total precipitation for drain pipe 48 effluent, 1975

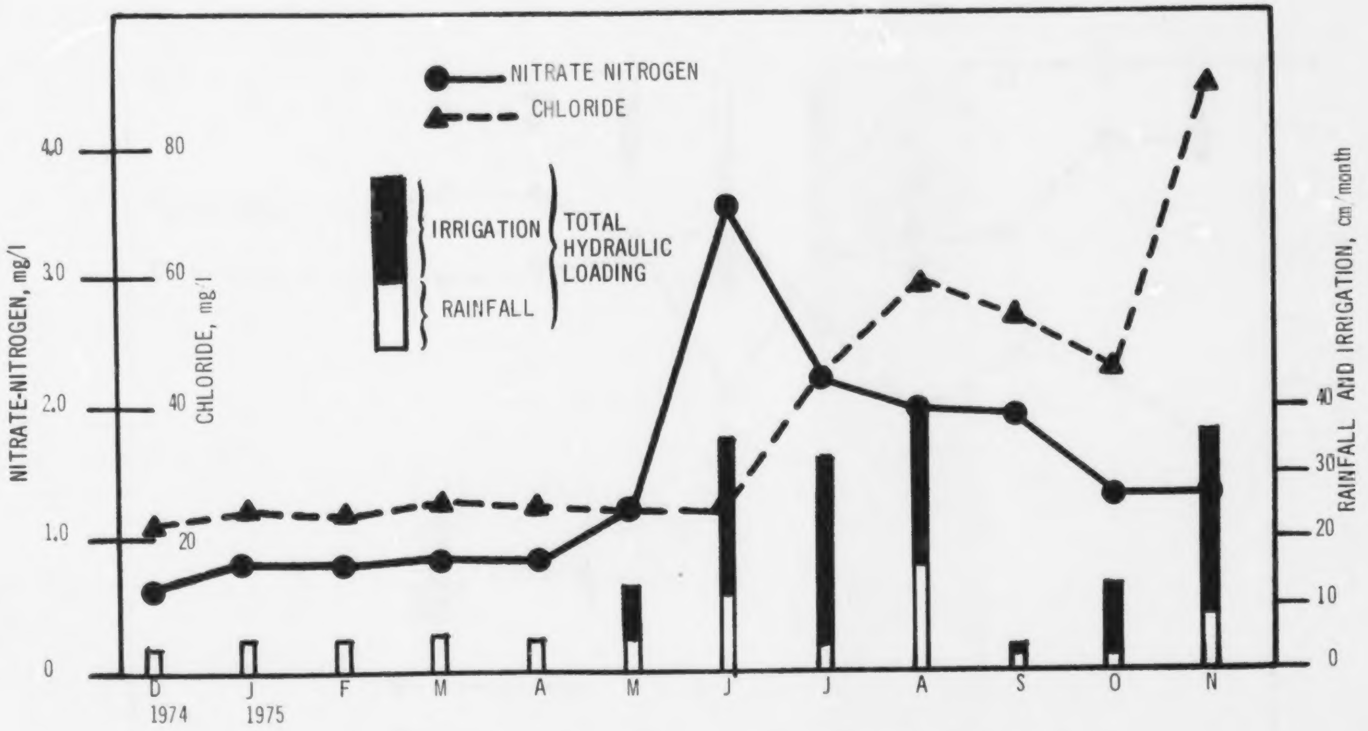

Figure 58. Nitrate, chloride and total precipitation for drain pipe 34 effluent, 1975

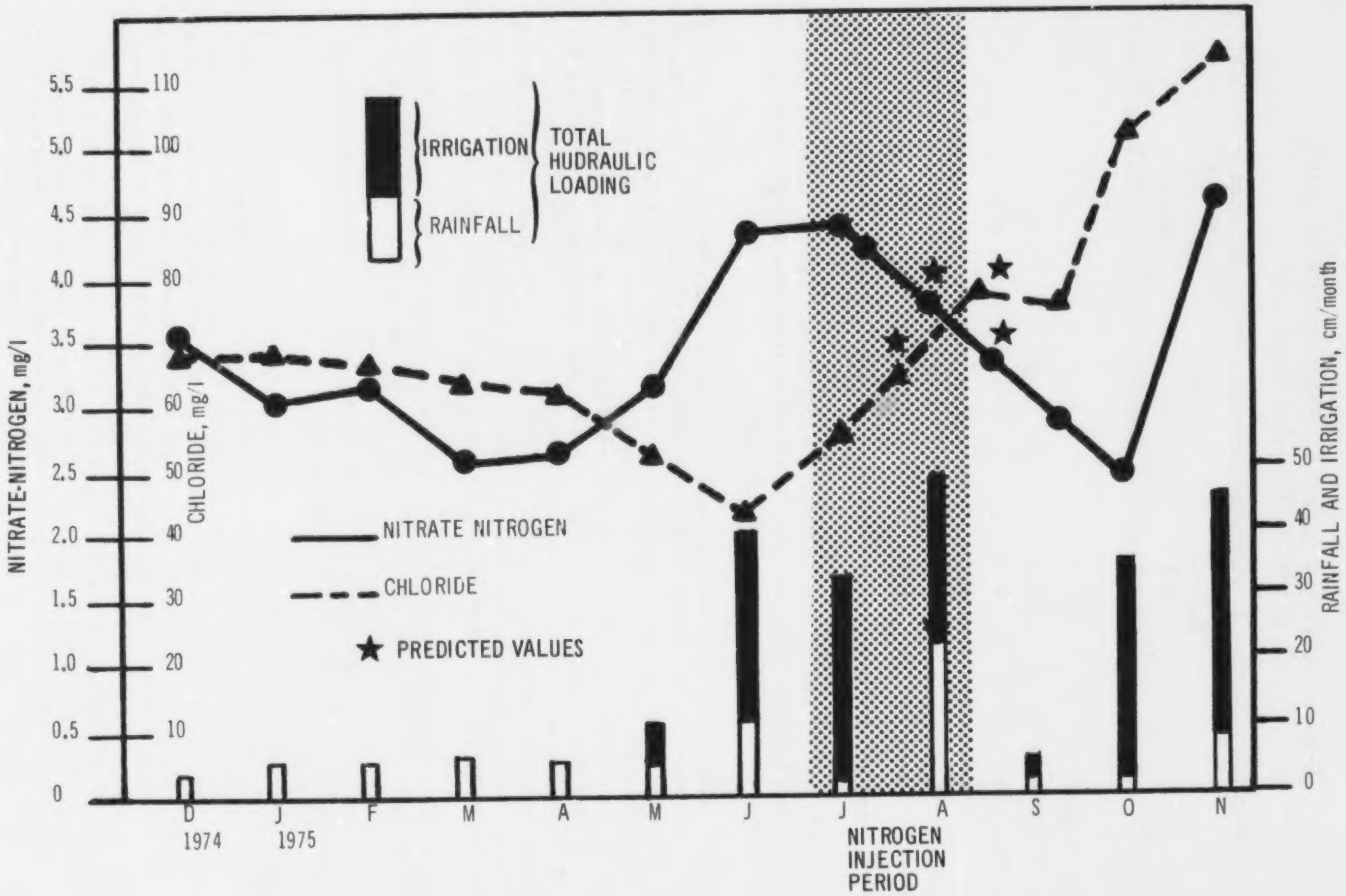

Figure 59. Nitrate, chloride and total precipitation for drain pipe 11 effluent, 1975

Table 48. AVERAGE NITRATE NITROGEN CONCENTRATIONS IN DRAIN PIPE LEACHATE, mg/l

Year/Months	Rubicon soil Drain pipe 11	Au Gres soil Drain pipe 19	Roscommon, Au Gres, and Granby soil Drain pipe 34	Roscommon soil Drain pipe 48
1974				
June - August	2.60	2.60	1.40	1.50
September - November	3.70	2.30	0.80	1.30
December - March, 1975	3.10	2.10	0.80	1.00
1975				
April - August	3.70	3.30	1.70	1.40
September - November	3.90	3.20	1.50	0.80

Drain pipes 11 and 19 showed some increase in nitrogen, and numbers 34 and 48 showed no change or slight decrease. After two years of irrigation, there were no significant increases in leached nitrogen from these representative soil types.

Through the winter of 1974 and early spring of 1975, the level of nitrate in the drain pipe discharge was low and steady. In late spring of 1975, the combination of irrigation and deep thaw increased nitrate leaching, but, by the end of summer, the level had again declined as the crop nutrient uptake became maximal. When irrigation was stopped for crop dry-down in early fall, the nitrate again dropped in the drainpipes, and later in the fall, when irrigation was resumed post-harvest, nitrate levels still declined in the percolate. With the approaching freeze of the 1975 winter, the nitrate levels were nearing the baseline concentration of the preceding year. The levels remained low from late fall through early spring because, with irrigation stopped, the sandy soils contained almost no moisture. With no moisture, there was no leaching. Also during this cold period, there was a minimum of conversion of ammonia and organic nitrogen to nitrates at the lower soil temperatures.

Nitrogen is at the hub of the process of wastewater renovation: it is received in effluent and recycled into corn. Continued monitoring and research may lead to better understanding of the effects of application of varying nitrogen concentrations with varying hydraulic loads to produce a minimal loss to drainage discharge. For statistical treatment of the data for drain pipe 19 in Table 48, see Figures 30 through 34 in Appendix C.

The yearly averages and ranges for selected parameters for 1975 drain pipe leachates are presented in Table 49. (For monthly averages of all commonly measured parameters, see Appendix C, Table 1.). Calcium, magnesium, iron, and manganese were increased in the 1975 measurements, with the most dramatic increases in drain pipes 34 and 48. Iron and manganese concentrations increased ten-fold and calcium-magnesium two-fold from the storage lagoons to the drain pipe discharge. In contrast, the levels of sodium dropped from storage lagoon to drainagepipe: from 144 mg/l, an average of east and west lagoon, to 42 mg/l, an average of drain pipes 11, 19, 34 and 48. Average potassium levels also dropped from 8.7 mg/l in the lagoons to 2.7 mg/l in the drainagepipes. These decreases were due to the exchange of sodium-potassium for calcium-magnesium. The elevated figures for iron and manganese were expected because of the extraordinary levels of these elements in those particular soils. There were substantial drops in phosphorus and ammonia nitrogen concentrations in the wastewater from storage to drainage dis-

Table 49. PROFILE OF DRAIN PIPE CHARACTERISTICS FOR 1975

Parameter	Rubicon soil Drain pipe 11		Au Gres soil Drain pipe 19		Roscommon, Au Gres and Granbv soils Drain pipe 34		Roscommon soil Drain pipe 48	
	Average	Range	Average	Range	Average	Range	Average	Range
Ca, ppm	45.8	38.2 → 58.0	61.0	45.4 → 74.9	81.4	51.8 →108	101	85.1 →118
Mg, ppm	13.6	11.6 → 16.3	17.8	10.3 → 22.9	24.3	15.1 → 37.0	35.2	25.3 → 55.6
Na, ppm	55.5	39.7 → 84.8	63.5	45.7 →122	26.7	0 → 67.9	23.3	0 → 41.3
K, ppm	2.20	1.53→ 3.61	3.57	2.52→ 5.99	2.24	1.64→ 3.20	2.62	2.00→ 3.28
Fe, ppm	0.11	0 → 1.01	0.53	0.22→ 0.90	7.11	0.15→ 14.1	23.1	0.08→ 46.1
Mn, ppm	0.01	0 → 0.01	0.09	0.02→ 0.12	0.30	0.27→ 0.34	0.41	0.36→ 0.44
Zn, ppm	0.03	0 → 0.11	0.02	0 → 0.11	0.03	0 → 0.23	0.05	0.01→ 0.45
P, ppm	0.02	0 → 0.06	0.01	0 → 0.04	0.01	0 → 0.05	0.01	0 → 0.05
NH_4-N, ppm	0.08	0 → 0.80	0.23	0 → 0.57	0.32	0.04→ 0.59	0.53	0.34→ 0.86
SO_4, ppm	52.0	31.0 →126	69.9	28.0 →115	187	77.0 →325	258	44.0 →600
Sp cond, μmhos/cm	503.	412 →658	613	502 →771	584	475 →706	694	568 →804
pH, SU	7.49	6.88→ 8.10	7.32	6.79→ 7.80	7.02	6.74→ 7.50	6.80	6.43→ 7.30
Color, APHA	15	2 → 40	33	5 → 60	93	30 →300	123	20 →750
Turb, FTU	0.40	0 → 2.70	2.50	0.60→ 5.20	17.8	1.50→ 50.0	32.0	3.10→ 85.0

For storage lagoon water quality data, Table 45, page 125 charge, with phosphorus decreasing from 1.5 to 0.01 mg/l and ammonia nitrogen decreasing from 6.0 to 0.50 mg/l. In drainpipes 34 and 48, there was significant increase in sulfate ion concentration from an average of 90 mg/l in the storage lagoons to 190 and 258 mg/l in the respective drainpipes. These surges were probably due to leaching of iron-rich sulfur compounds. However, drain pipes 11 and 19 showed a decrease in sufate ion, a trend which suggests that in the near future, when equilibrium has been established, a reduction in the iron and sulfate concentrations will probably occur.

The most dramatic decrease was in color from more than 1300 units in the influent to 15 to 30 units in drain pipes 11 and 19. The color of 100 to 120 in drain pipes 34 and 48 was due to leached iron. There was also a decrease in the conductivity. The pH remained around 7.0.

These preliminary drain pipe results from two irrigation seasons prove that the "living filter" concept is valid for removing important pollutants from wastewater. As to the effectiveness of the system on a long-term basis, further work is necessary to define unknowns such as the fate of nitrogen, potential accumulation of phosphorus and metals, and other physico-chemical characteristics of soil which may be affected by sustained wastewater irrigation.

Water Leaving the System

The two major routes for water to leave the site are via interception ditch discharges and via the drainage canal outfalls.

Interception Ditches

The detailed layout of the interception ditches is described in the section dealing with design, but, in brief, there are two main divisions: one which borders the north and east perimeter of the storage lagoons, called the north ditch; and one on the south and west perimeter, called the south ditch. The purpose of the interception ditches is to intercept the flow of groundwater from beneath the lagoons, thus preventing flow to outlying areas. Water from the north ditch is pumped to the north outfall which joins Mosquito Creek. The south ditch discharges to a branch of Big Black Creek.

Results of monitoring for the period of August, 1974, to December, 1975, are plotted in Figures 60 and 61 with discharge volumes, BOD_5, suspended solids, nitrate and ammonia included for the north and south ditches.

In Figure 60, the discharge volume peaked in June, 1974, at about 51.3 TCMD and dropped through December, 1974. From then through December, 1975, the discharge volume remained at a plateau of about 20.9 TCMD. The south ditch was roughly parallel, with a 1974 peak in April at 66.5 TCMD and gradual decrease to 22.8 TCMD. The south ditch peak discharge volume occurred during the initial filling of the lagoons at a period of maximum hydraulic head. It was at this time that both lagoons were filled to the highest storage volumes, about 15 cm above high water level. In 1975, the lagoon levels peaked at about 35 cm below high water level. As indicated in Figure 62 the average irrigation ditch pumping volume corresponded fairly closely to lagoon storage elevation, so it would still be premature to draw conclusions on the amount of lagoon sealing. Further observations will be necessary to clarify the relationship between lagoon level and interception ditch volumes.

Interception ditch suspended solids and BOD_5 data from June, 1974, to December, 1975, showed no clear trends. Average suspended solids in each ditch was 13 mg/l, most of which was leached iron and algae. The BOD_5 averaged about 8 mg/l in the north and about 4 mg/l in the south.

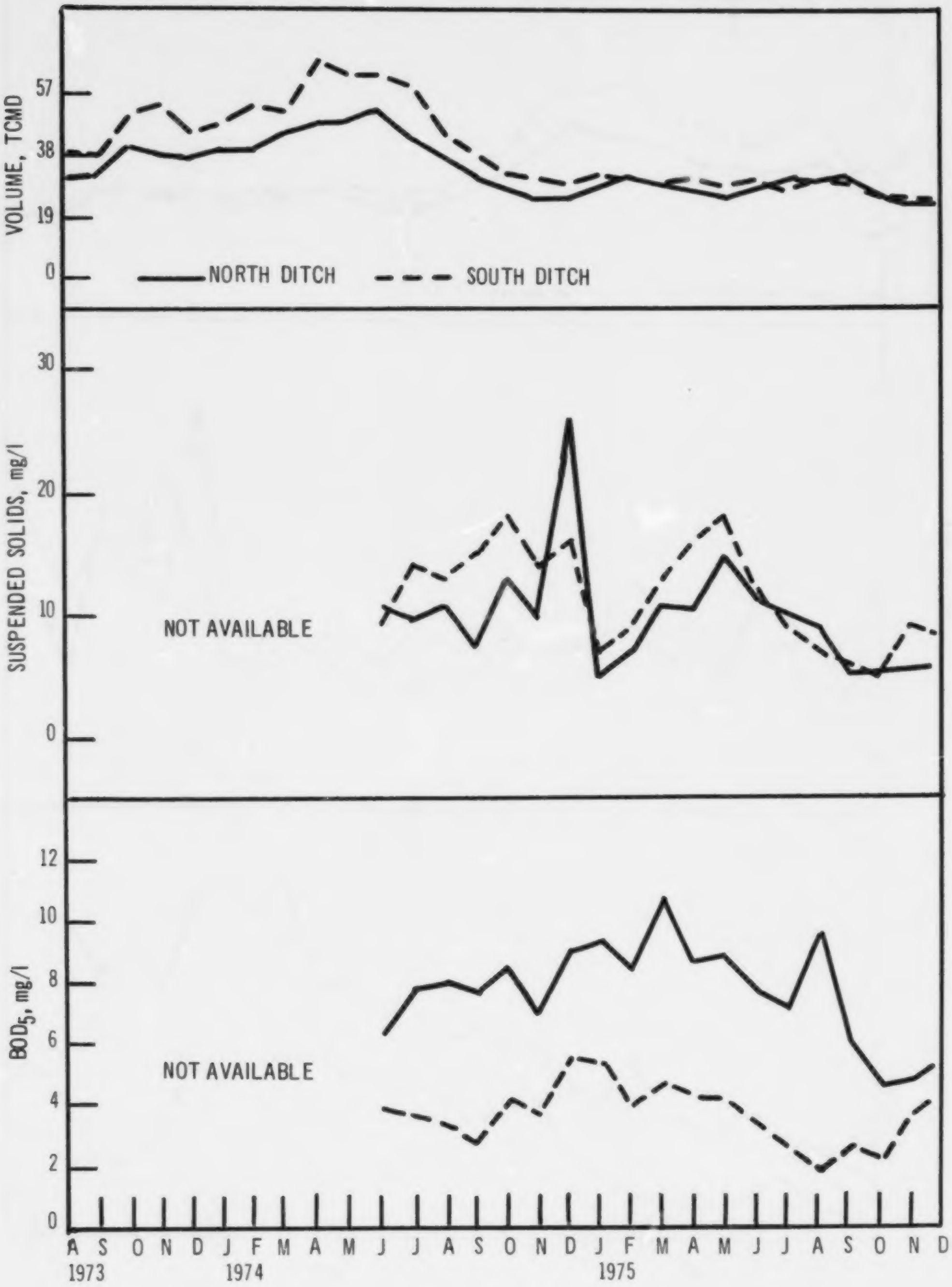

Figure 60. Average volume, suspended solids and five-day biochemical oxygen demand for north and south interception ditches, 1973-1975

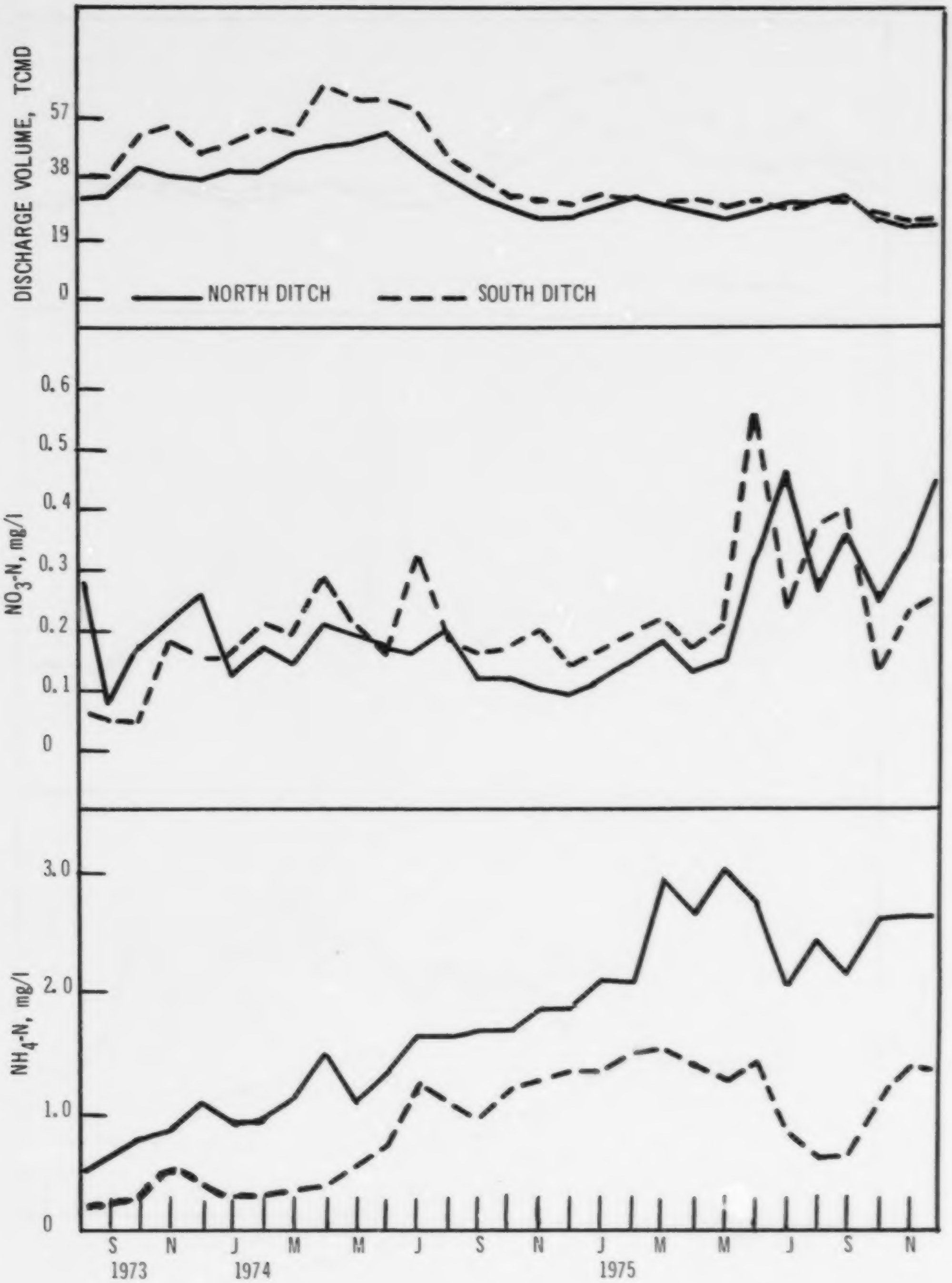

Figure 61. Average volume, nitrate, and ammonia in north and south interception ditches, 1973-1975

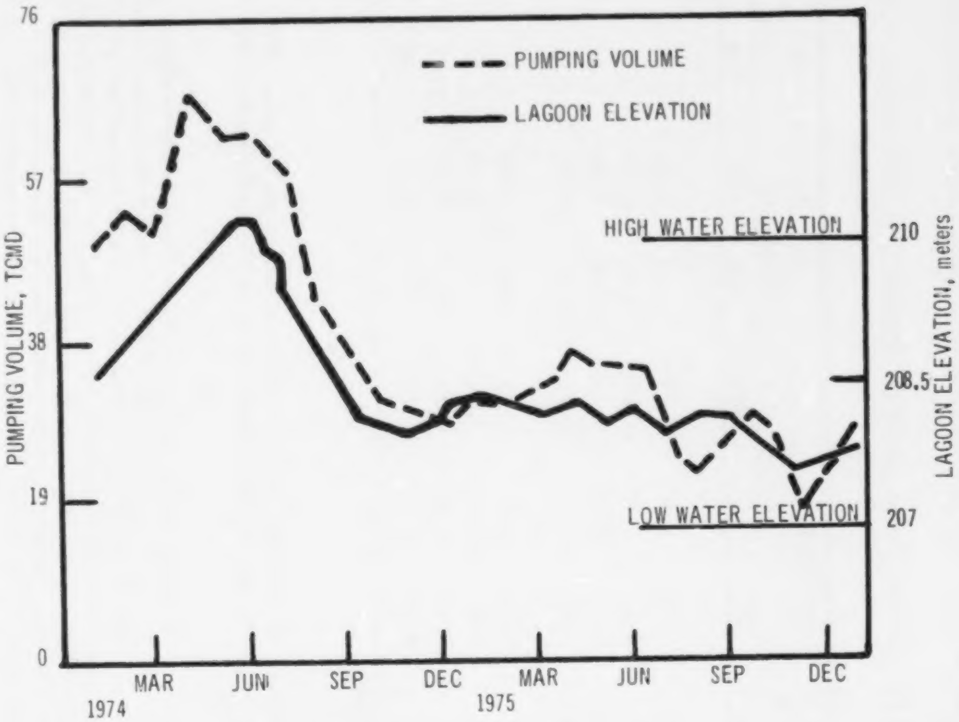

Figure 62. Interception ditch pumping volume and storage lagoon elevation, 1974-1975

The trend of increasing nitrate-ammonia was due to a combination of lagoon hydraulic head and interception ditch water volume. As the lagoons were being filled in 1973-1974, all interception ditch discharge was being pumped back into the lagoons. With long detention and high water level, there was dilution and denitrification both contributing to lowered nitrogen values. Into 1975, lagoon water levels were lower, and interception ditch water was discharged into the drainage canals. The result was a smaller water volume with less dilution, giving ammonia nitrogen concentrations ranging from about 0.5mg/l to 2.5mg/l in the north and 1.0mg/l in the south ditch. Similarly, there was a very slight increase in the nitrate concentrations in both ditches. Table 50 below shows the monthly averages taken quarterly with standard deviations for nitrate nitrogen and ammonia nitrogen in the north and south interception ditches for 1974-1975.

Table 50. NITRATE NITROGEN AND AMMONIA NITROGEN IN THE NORTH AND SOUTH INTERCEPTION DITCHES, 1974, 1975, mg/l

	Nitrate nitrogen				Ammonia nitrogen			
	North ditch		South ditch		North ditch		South ditch	
Year/month	Avg	SD[a]	Avg	SD[a]	Avg	SD[a]	Avg	SD[a]
1974								
March	0.14	0.04	0.19	0.04	1.08	0.33	0.36	0.11
June	0.17	0.12	0.16	0.07	1.38	0.23	0.71	0.14
September	0.12	0.05	0.16	0.07	1.67	0.08	0.96	0.18
December	0.08	0.02	0.14	0.01	1.86	0.16	1.35	0.11
1975								
March	0.18	0.10	0.21	0.08	2.96	0.63	1.52	0.13
June	0.32	0.44	0.33	0.30	2.79	0.65	1.35	0.16
September	0.36	0.29	0.40	0.08	2.18	0.31	0.62	0.18
December	0.43	0.13	0.20	0.05	2.80	0.67	1.30	0.19

[a] SD = Standard Deviation

Outfalls

From the drainage canals, the leachate is discharged to surface waters via either of two outfalls, one in the north which empties into Mosquito Creek and one in the south which empties into Big Black Creek. See Figure 5.

The presentation of the outfall water quality is the same as for the interception ditches and drainage canals. Monthly averages for suspended solids, BOD_5, ammonia nitrogen and nitrate nitrogen are plotted below the flowrates in TCMD. In Figures 63 and 64 the fluctuations in the flowrate from the south outfall were direct responses to irrigation schedules. The abbreviated plot for the north outfall was caused by the delay in the installations of the USGA flow gauges. Until the gauge was installed, there were no records of the gravity flow, but the pattern of discharge was assumed to be similar to that of the south. The ranges in discharge volumes were from 9.5 to 19 TCMD in the south and from 53.2 to 175 in the north.

Suspended solids concentrations were stable in the north outfall, ranging from 5 to 12mg/l, but in the south, the range was from 21 to 36mg/l, the higher concentrations corresponding well with periods of irrigation. These higher values at the south outfall were predicted because of the high iron content in these irrigation circles.

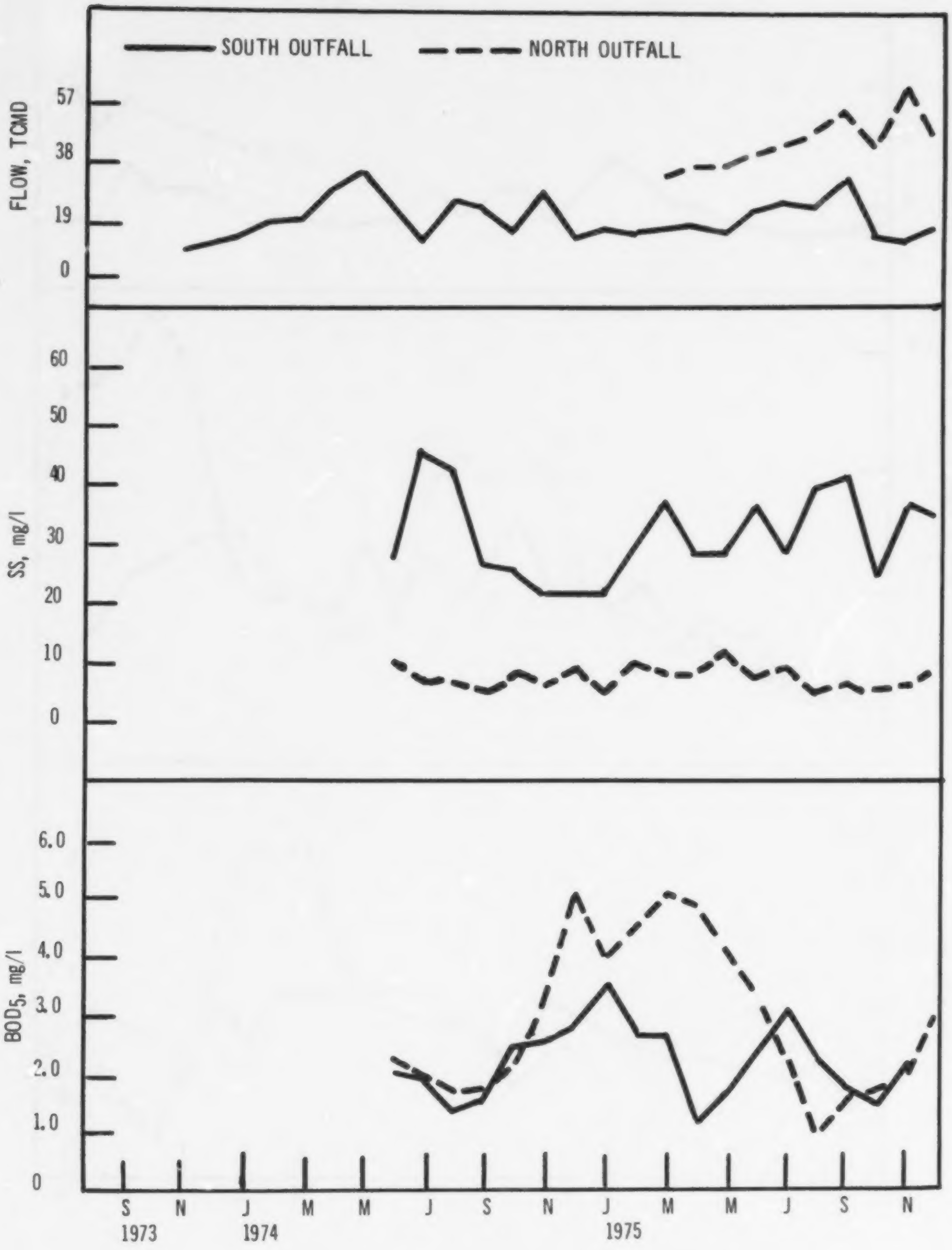

Figure 63. Flow, suspended solids, and five-day biochemical oxygen demand in north and south outfalls, 1973-1975

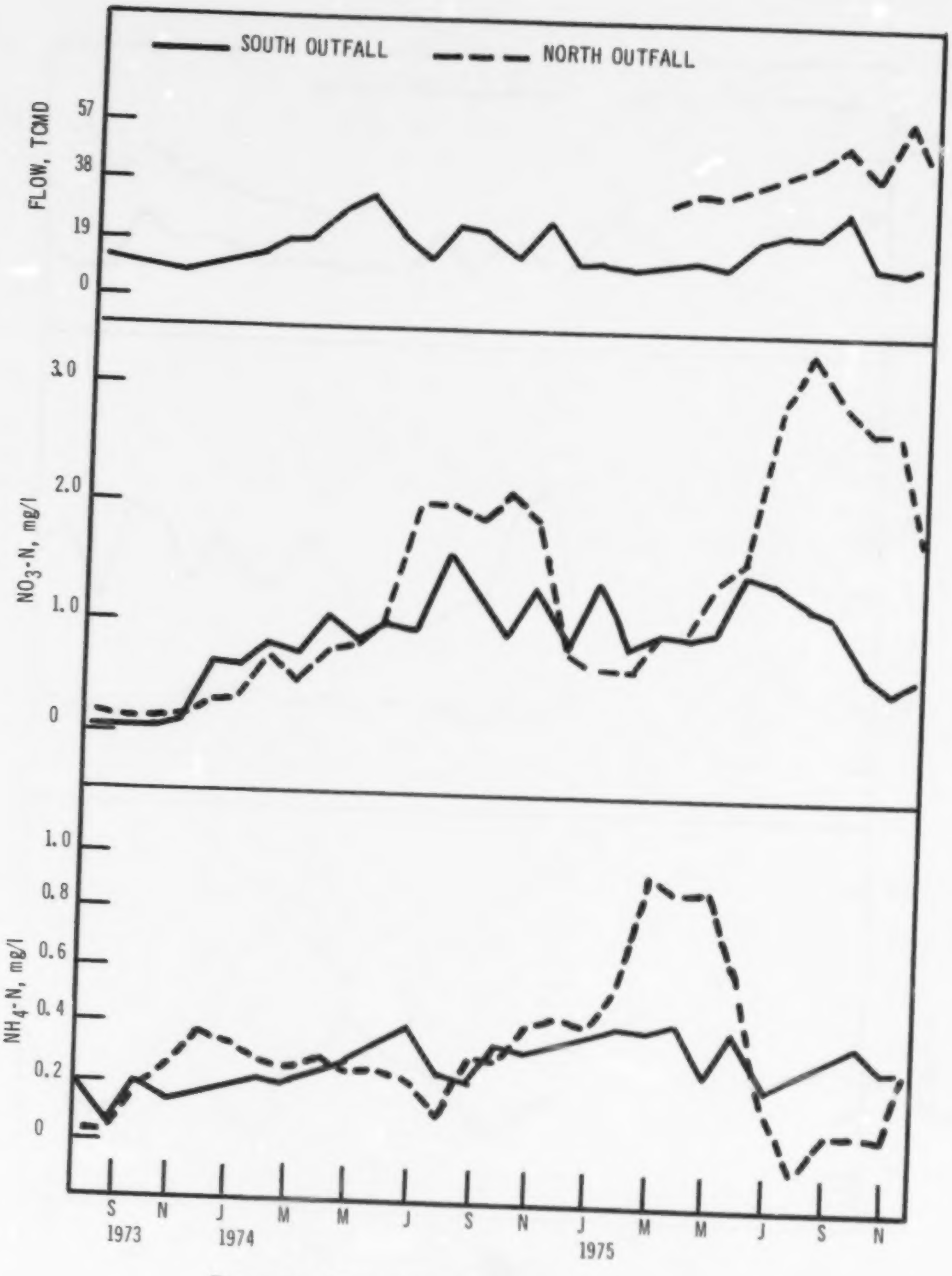

Figure 64. Flow, nitrate nitrogen, and ammonia nitrogen in north and south outfalls, 1973-1975

Outfall BOD_5 concentrations were generally low, but the fluctuations which were measured were in indirect correlation with irrigation schedules. During periods of irrigation, the lower BOD_5 ranges were about 1 to 2 mg/l, but as irrigation was shut down, BOD_5 increased to about 3.5 mg/l in the south and to 5 mg/l in the north.

Outfall nitrate nitrogen concentrations are graphed in Figure 64 and are directly correlated with the irrigation schedule. The levels ranged in the north from about 0.2 to 3.4 mg/l and in the south from about 0.1 to 1.5 mg/l, concentrations which are far below those attained by conventional or other advanced wastewater treatment systems.

Ammonia nitrogen, like BOD_5, decreased with irrigation and increased during periods of shutdown. The widest range in concentrations was found in the north outfall – about 0.1 to 1.2 mg/l – and it was thought to be due to changes in redox potentials and hydrogen ion concentrations in the soil profile. In the case of the south outfall, the range was 0.3 to 0.6 mg/l. Part of the difference between the concentrations at the two outfalls was attributed to the fact that the south fields consistently received less irrigation; this fact simultaneously contrasted north and south while lending apparent stability to the discharge concentrations in the south.

The concentrations of ammonia nitrogen were also well below levels achieved by conventional or other advanced wastewater treatment systems.

Although the influent levels of ammonia nitrogen and total nitrogen are very low compared to wastewater at most other locations, the addition of supplemental nitrogen to the wastewater during the irrigation season brings the levels equal to, or higher than, those in most wastewater influent. Because the nitrogen supplementation alters levels so drastically, it was decided to present the outfall data in Table 51 for months just before supplemental nitrogen application and just after the irrigation season, the months of March and December. For a plot of the monthly averages of nitrogen and ammonia nitrogen 1973-1975, refer to Figure 64.

Table 51. DAILY AVERAGE OF NO_3-N AND BOD_5 IN OUTFALL DISCHARGE, MARCH AND DECEMBER, 1974 AND 1975

	BOD_5, mg/l		NO_3, mg/l	
Outfall/date	Avg	SD[a]	Avg	SD[a]
North outfall				
1974 March	NA	NA	0.50	0.10
December	5.10	1.70	0.80	0.30
1975 March	5.10	0.90	0.90	0.20
December	3.20	1.30	1.20	0.20
South outfall				
1974 March	NA	NA	0.70	0.30
December	2.90	1.30	0.80	0.20
1975 March	2.70	1.70	0.80	0.30
December	2.80	0.50	0.60	0.30

[a] SD = Standard Deviation

Again, as in the case of ammonia nitrogen, the BOD$_5$ was sometimes slightly higher in the drainage ditches than at the point of egress from the drainagepipes, probably due to the same factors – contributions of plants and wildlife at or in the ditches. But at 98 and 99 percent removal, the BOD$_5$ levels at the outfalls were considered extraordinarily low.

Summary Tables

Comparison of WMS 1975 discharge water quality with the standards established by the National Pollution Discharge Elimination System (NPDES) indicates that during 1975 system performance exceeded the quality demands of both the NPDES and the system's original design specifications for BOD$_5$, total phosphate, and total nitrogen. See Table 52. Although the suspended solids were below the NPDES limits in the north outfall, the level in the south outfall was exceptionally high due to the remarkably high iron concentrations leached from the southern fields – not due to factors intrinsic to the wastewater treatment protocol.

Elevation of fecal coliform counts above recommended limits was attributed to two factors: the ununiform emptying of the discharge canal due to a bottleneck effect caused by sand and weeds; and the canals often hosted flocks of waterfowl which, it was suspected, did not always leave the canals before defecating. The low coliform counts in the drainage pipesprecluded other conclusions.

The summary of 1975 treatment performance data for 29 parameters in Table 53 is essentially a flow diagram which presents yearly averages and ranges on wastewater measurements from the time it arrives at the project, through biological treatment and storage, through the drain pipes of representative soils, and up to the point of discharge into surface waters. It is included as a convenient reference to allow gross assessments of changing water quality through the steps in treatment and to allow comparisons among years. Summary tables for 1973 and 1974 are in Appendix C, Table 2.

Treatment Performance Summary and Recommendations

The Muskegon system as operated in 1975 effectively and satisfactorily removed all wastewater parameters measures. Although the levels of nitrogen in the drainagepipes and at the outfalls were low, it is to the study of nitrogen dynamics that more research should be devoted. Studies on high density crop planting with supplemental nitrogen may prove even more effective in total nitrogen removal through the denser root network and, incidentally, may contribute to cost-effectiveness by higher crop yields. Other areas of investigation should include long-term views of the cation-exchange capacity of the soils, with an eye toward prediction of the timing of the achievement of equilibrium conditions for pollutant removal and how this timetable may impact on the potential industrial expansion of the region. And studies are recommended on the increased efficiency of operating the facility to achieve the most cost-effective manpower and overall energy use in the relationship between the three major phases of operations: biological treatment, impoundment and soil-crop-management.

Table 52. COMPARISONS OF WMS 1975 WATER DISCHARGE CHARACTERISTICS WITH DESIGN SPECIFICATIONS AND NPDES LIMITS

Parameter	System design	NPDES limit	1975 discharge	
			North outfall	South outfall
BOD_5	4.00 mg/l	4.00 mg/l	3.30 mg/l	2.30 mg/l
Suspended solids	4.00 mg/l	10.0 mg/l	7.00 mg/l	31.0 mg/l[a]
Total phosphorus	0.50 mg/l	0.50 mg/l	0.03 mg/l	0.03 mg/l
Ammonia nitrogen	0.50 mg/l	Not specified	0.61 mg/l	0.54 mg/l
Nitrate nitrogen	5.00 mg/l	Not specified	1.89 mg/l	0.99 mg/l
Fecal coliform	0	200/100 ml	$1.0 \times 10^{0} \rightarrow$ 5.0×10^{3}[b]	$1.0 \times 10^{0} \rightarrow$ 5.6×10^{3}[b]

[a] Elevated value due to leaching of iron

[b] Higher value of range due to fecal deposits of waterfowl

Table 53. TREATMENT PERFORMANCE STUDY, 1975

Parameter	Units	Influent		Effluent from biological treatment	
		Average	Range	Average	Range
BOD_5	ppm	205	102 → 448	81.4	10.0 → 245
DO	ppm	No data		0.79	0 → 6.45
Temperature	°C	23.5	12.0 → 31.0	19.5	9.00 → 28.5
pH	SU	7.31	6.20 → 11.2	7.45	7.00 → 8.18
Sp cond	μmhos/cm	1049	580 → 3300	1010	697 → 1260
Color	APHA	No data		No data	
Turbidity	FTU	No data		No data	
TS	ppm	1093	518 → 2418	914	441 → 1260
TVS	ppm	460	158 → 1634	339	122 → 660
SS	ppm	249	0 → 1220	144	4 → 366
COD	ppm	545	92.0 → 1948	375	85.0 → 737
TOC	ppm	107	50.0 → 318	73.0	29.0 → 191
NH_4-N	ppm	6.12	0.20 → 24.0	4.12	0 → 12.9
NO_3-N	ppm	No data		0.11	0 → 7.20
PO_4-P	ppm	1.56	0.10 → 4.40	1.79	0.87 → 3.26
SO_4	ppm	75.0	8.00 → 300	91.0	22.0 → 241
Cl	ppm	182	45.0 → 366	177	67.0 → 244
Na	ppm	166	68.9 → 1010	165	118 → 239
Ca	ppm	73.6	48.3 → 142	69.0	50.6 → 118
Mg	ppm	14.3	10.5 → 20.3	15.1	8.61 → 19.3
K	ppm	10.5	5.90 → 33.6	11.1	3.92 → 18.9
Fe	ppm	0.79	0.30 → 5.00	0.74	0.39 → 1.42
Zn	ppm	0.57	0 → 3.90	0.41	0.05 → 3.65
Mn	ppm	0.28	0.10 → 1.00	0.25	0.16 → 0.50
Total coli	Colonies/100ml	No data		No data	
Fecal coli	Colonies/100 ml	No data		No data	
Fecal strep	Colonies/100 ml	No data		No data	
TKN	ppm	8.24	1.00 → 25.7	8.87	1.20 → 17.0
TP	ppm	2.38	0.50 → 4.50	2.65	1.40 → 5.20

Table 53 (continued). TREATMENT PERFORMANCE STUDY, 1975

Parameter	Units	East storage lagoon		West storage lagoon	
		Average	Range	Average	Range
BOD_5	ppm	12.4	0 → 42.0	13.3	2.00 → 38.0
DO	ppm	6.00	0 → 11.2	5.40	0 → 14.2
Temperature	°C	11.5	0.50 → 27.5	11.8	0.50 → 27.0
pH	SU	7.86	7.30 → 8.60	7.72	7.20 → 8.30
Sp cond	μmhos/cm	872	505 → 1155	777	361 → 1077
Color	APHA	No data		No data	
Turbidity	FTU	No data		No data	
TS	ppm	728	408 → 1074	654	178 → 952
TVS	ppm	228	50.0 → 646	222	92.0 → 704
SS	ppm	23.0	0 → 306	18	1.00 → 92.0
COD	ppm	131	36.0 → 254	104	8.00 → 210
TOC	ppm	43.5	14.9 → 97.0	32.4	12.0 → 104
NH_4-N	ppm	2.51	0.02 → 7.88	2.29	0 → 8.96
NO_3-N	ppm	1.35	0.01 → 4.85	0.84	0 → 4.79
PO_4-P	ppm	1.34	0.03 → 2.28	1.01	0 → 5.07
SO_4	ppm	101	33.0 → 1030	78.0	23.0 → 198
Cl	ppm	169	62.0 → 217	138	51.0 → 184
Na	ppm	164	144 → 187	125	81.1 → 177
Ca	ppm	60.3	52.9 → 78.0	56.3	46.0 → 66.4
Mg	ppm	15.8	13.5 → 21.3	16.2	13.3 → 21.0
K	ppm	9.82	8.90 → 11.0	7.53	5.60 → 18.5
Fe	ppm	1.17	0.90 → 1.50	0.86	0.30 → 3.10
Zn	ppm	0.12	0.10 → 0.20	0.09	0 → 0.10
Mn	ppm	0.22	0.20 → 0.30	0.09	0 → 0.20
Total coli	Colonies/100 ml		$1.0\times10^{2} \rightarrow 2.1\times10^{7}$		$1.5\times10^{2} \rightarrow 1.2\times10^{8}$
Fecal coli	Colonies/100 ml		$4.0\times10^{0} \rightarrow 1.4\times10^{5}$		$4.0\times10^{0} \rightarrow 1.2\times10^{6}$
Fecal strep	Colonies/100 ml		$2.0\times10^{0} \rightarrow 2.4\times10^{4}$		$2.0\times10^{0} \rightarrow 3.8\times10^{4}$
TKN	ppm	4.57	0.60 → 15.8	4.52	0.60 → 9.60
TP	ppm	1.46	0.40 → 2.70	1.41	0 → 3.51

Table 53 (continued). TREATMENT PERFORMANCE STUDY, 1975

Parameter	Units	Mosquito Creek		Big Black Creek	
		Average	Range	Average	Range
BOD$_5$	ppm	3.30	0 → 8.30	2.30	0 → 9.00
DO	ppm	6.18	2.40 → 11.2	3.41	0.20 → 7.40
Temperature	°C	9.90	1.00 → 19.0	9.70	3.00 → 16.0
pH	SU	7.51	6.50 → 8.10	7.00	6.50 → 7.80
Sp cond	μmhos/cm	574	430 → 708	670	480 → 795
Color	APHA	No data		No data	
Turbidity	FTU	No data		No data	
TS	ppm	466	102 → 724	691	317 → 954
TVS	ppm	172	72 → 328	205	108 → 484
SS	ppm	7.00	0 → 49.0	31.0	6.00 → 140
COD	ppm	33.0	0 → 146	23.0	0 → 116
TOC	ppm	15.1	5.70 → 43.5	11.5	4.60 → 49.5
NH_4-N	ppm	0.61	0.05 → 1.56	0.54	0.30 → 1.79
NO_3-N	ppm	1.89	0.42 → 4.70	0.99	0.13 → 2.37
PO_4-P	ppm	0.03	0 → 0.64	0.02	0 → 0.11
SO_4	ppm	81.0	35.0 → 273	284	66.0 → 685
Cl	ppm	78.0	12.0 → 115	32.0	13.0 → 59.0
Na	ppm	66.2	51.2 → 130	21.0	10.9 → 52.8
Ca	ppm	61.4	52.3 → 75.0	107	61.8 → 174
Mg	ppm	18.2	15.0 → 23.1	38.3	13.8 → 51.5
K	ppm	4.05	2.59 → 5.64	2.76	2.10 → 3.70
Fe	ppm	1.03	0.03 → 3.84	17.4	5.98 → 28.1
Zn	ppm	0.07	0.01 → 0.35	0.11	0.02 → 0.93
Mn	ppm	0.11	0 → 0.16	0.38	0.34 → 0.49
Total coli	Colonies/100 ml		$< 1.0\times10^0 \rightarrow 9.6\times10^4$		$1.0\times10^0 \rightarrow 2.6\times10^4$
Fecal coli	Colonies/100 ml		$< 1.0\times10^0 \rightarrow 4.8\times10^3$		$1.0\times10^0 \rightarrow 5.6\times10^2$
Fecal strep	Colonies/100 ml		No data		No data
TKN	ppm		No data		No data
TP	ppm		No data		No data

Table 53 (continued). TREATMENT PERFORMANCE STUDY, 1975

Parameter	Units	Drain pipe 11 Average	Drain pipe 11 Range	Drain pipe 19 Average	Drain pipe 19 Range
BOD$_5$	ppm	0.80	0.10 → 1.60	1.10	0 → 3.70
DO	ppm	No data		No data	
Temperature	°C	No data		No data	
pH	SU	7.49	6.88 → 8.10	7.32	6.79 → 7.80
Sp cond	μmhos/cm	503	412 → 658	613	502 → 771
Color	APHA	15.0	2.00 → 40.0	33.0	5.00 → 60.0
Turbidity	FTU	0.40	0 → 2.70	2.50	0.60 → 5.20
TS	ppm	No data		No data	
TVS	ppm	No data		No data	
SS	ppm	No data		No data	
COD	ppm	No data		No data	
TOC	ppm	4.20	1.80 → 17.3	14.9	4.50 → 46.2
NH$_4$-N	ppm	0.08	0 → 0.80	0.23	0 → 0.57
NO$_3$-N	ppm	3.44	1.30 → 4.82	2.88	1.12 → 4.73
PO$_4$-P	ppm	0.02	0 → 0.06	0.01	0 → 0.04
SO$_4$	ppm	52.0	31.0 → 126	70.0	28.0 → 115
Cl	ppm	72.0	27.0 → 123	87.0	35.0 → 143
Na	ppm	55.5	39.7 → 84.8	63.5	45.7 → 122
Ca	ppm	45.8	38.2 → 58.0	61.0	45.4 → 74.9
Mg	ppm	13.6	11.6 → 16.3	17.8	10.3 → 24.4
K	ppm	2.24	1.53 → 3.61	3.57	2.52 → 5.99
Fe	ppm	0.11	0 → 1.01	0.53	0.22 → 0.90
Zn	ppm	0.03	0 → 0.11	0.02	0 → 0.11
Mn	ppm	0.01	0 → 0.01	0.09	0.02 → 0.12
Total coli	Colonies/100 ml		$< 1.0\times10^0 \rightarrow 7.4\times10^1$		$< 1.0\times10^0 \rightarrow 1.5\times10^2$
Fecal coli	Colonies/100 ml		$< 1.0\times10^0 \rightarrow 1.1\times10^1$		$< 1.0\times10^0 \rightarrow 1.7\times10^1$
Fecal strep	Colonies/100 ml		$< 1.0\times10^0 \rightarrow 4.7\times10^1$		$< 1.0\times10^0 \rightarrow 1.5\times10^1$
TKN	ppm	No data		No data	
TP	ppm	No data		No data	

Table 53 (continued). TREATMENT PERFORMANCE STUDY, 1975

Parameter	Units	Drain pipe 34		Drain pipe 48	
		Average	Range	Average	Range
BOD_5	ppm	1.10	0.30 → 3.00	1.70	4.00 → 4.00
DO	ppm	No data		No data	
Temperature	°C	No data		No data	
pH	SU	7.02	6.74 → 7.50	6.80	6.43 → 7.30
Sp cond	μmhos/cm	584	475 → 706	694	568 → 804
Color	APHA	93.0	30.0 → 480	123	20.0 → 750
Turbidity	FTU	17.8	1.50 → 50.0	32.0	3.10 → 85.0
TS	ppm	No data		No data	
TVS	ppm	No data		No data	
SS	ppm	No data		No data	
COD	ppm	No data		No data	
TOC	ppm	15.0	4.20 → 42.2	12.4	4.40 → 50.0
NH_4-N	ppm	0.32	0.04 → 0.59	0.53	0.34 → 0.86
NO_3-N	ppm	1.46	0.21 → 8.87	1.17	0.41 → 2.53
PO_4-P	ppm	0.01	0 → 0.05	0.01	0 → 0.05
SO_4	ppm	187	77.0 → 325	258	44.0 → 600
Cl	ppm	41.9	9.80 → 95.0	41.0	13.0 → 68.0
Na	ppm	26.7	0 → 67.9	23.3	0 → 41.3
Ca	ppm	81.4	51.8 → 108	102	85.1 → 118
Mg	ppm	24.4	15.1 → 37.0	35.3	25.3 → 55.6
K	ppm	2.24	1.64 → 3.20	2.62	2.00 → 3.28
Fe	ppm	7.11	0.15 → 14.1	23.1	0.08 → 46.1
Zn	ppm	0.03	0 → 0.23	0.05	0.01 → 0.45
Mn	ppm	0.30	0.27 → 0.34	0.41	0.36 → 0.44
Total coli	Colonies/100 ml		$< 1.0\times10^{0} \rightarrow 1.6\times10^{2}$		$< 1.0\times10^{0} \rightarrow 1.7\times10^{2}$
Fecal coli	Colonies/100 ml		$< 1.0\times10^{0} \rightarrow 3.2\times10^{1}$		$< 1.0\times10^{0} \rightarrow 1.1\times10^{1}$
Fecal strep	Colonies/100 ml		$< 1.0\times10^{0} \rightarrow 2.8\times10^{1}$		$< 1.0\times10^{0} \rightarrow 2.7\times10^{2}$
TKN	ppm	No data		No data	
TP	ppm	No data		No data	

SECTION 8

MONITORING OF GROUND AND SURFACE WATER QUALITY

GROUNDWATER

The purpose of groundwater monitoring was to evaluate the effects of the storage lagoons and irrigation on the quality of the surrounding groundwater. Access to the groundwater was provided by two series of "observation wells," one group of lagoon seepage wells and one group of perimeter wells. The exact layout of these wells is illustrated in Figure 65.

The lagoon seepage wells surround the storage lagoons on the west, southwest and southern aspects, in accordance with the known directions of groundwater flow determined before construction of the lagoons. The sampling of these 233 wells was done two or three times per year, with the water sample withdrawn after the well was pumped for ten minutes. Laboratory analyses included chloride, nitrate, phosphate, total coliform and conductivity.

The perimeter wells surround the area under irrigation and are scattered along the site boundaries. These 56 wells were sampled in the same way as the lagoon seepage wells, but the frequency of sampling was monthly.

In the case of each group of wells, the number installed was not the number functioning by the end of 1975. In Appendix D, Tables 1 and 2 list along with individual well number the depth and current status of all of the perimeter wells and the lagoon seepage wells; the reasons for well loss or well failure are indicated. Losses were due to:

(a) finishing construction procedures such as land clearing, installation of fencing, etc.

(b) construction of solid waste facility, damaging or destroying some lagoon seepage wells

(c) brush fires damaging lagoon seepage wells

(d) vandalism, including automobile and snowmobile damage, gunfire and other malicious destruction

(e) permanent dry conditions since installation

(f) erratic dry conditions, often without pattern

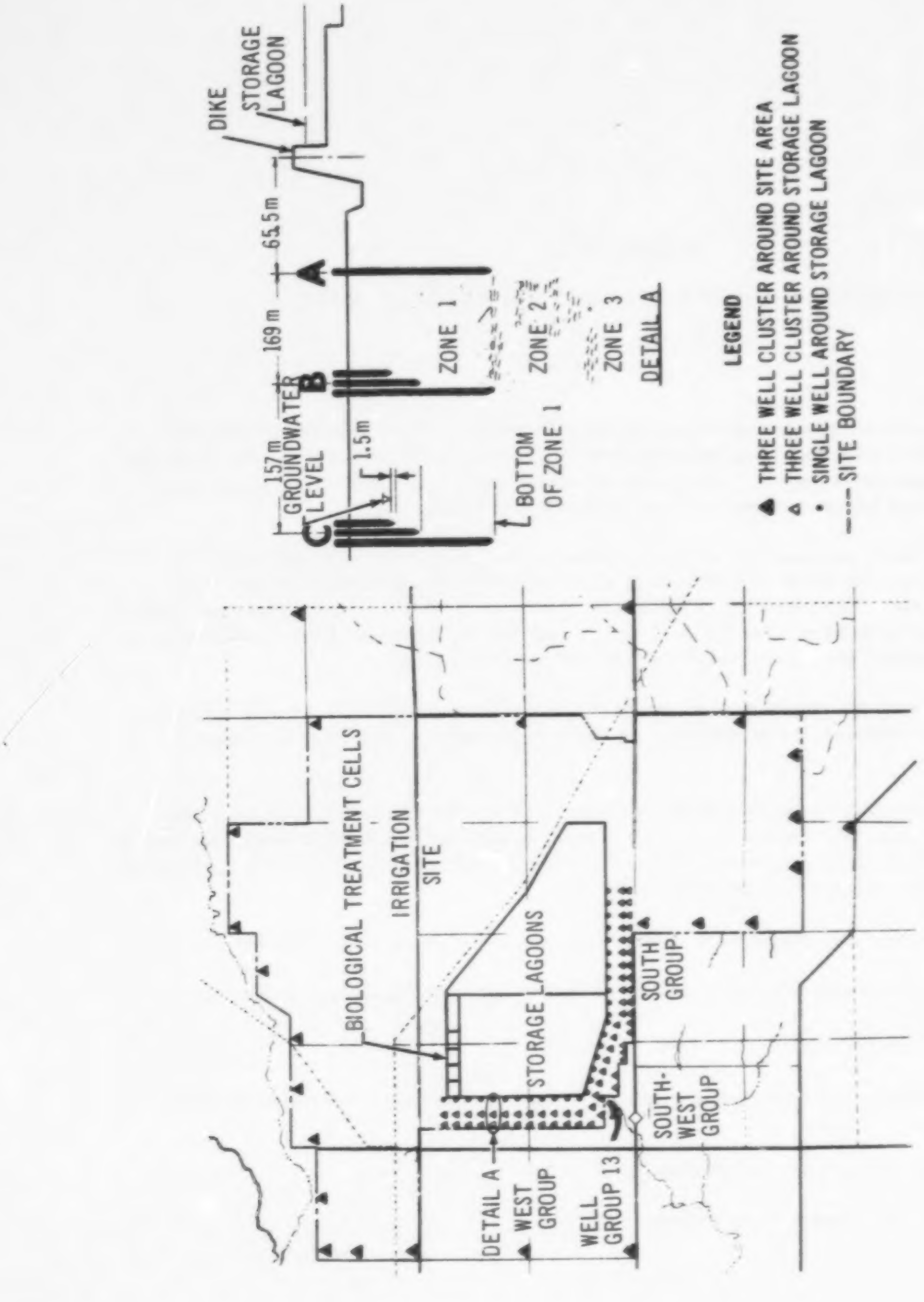

Figure 65. Groundwater observation points

Lagoon Seepage Wells

The purpose of these wells is to allow the evaluation of the performance of the interception ditch around the storage lagoon area.

There are approximately 33 groups of wells with seven wells in each group, arranged as in Figure 65. The wells nearest the storage lagoons are the Group A wells, single wells drilled to the bottom of "Zone I." The Group B wells are in clusters of three. The B-1 wells are 1.7 m into the groundwater table, the B-3 wells are drilled to the bottom of "Zone I," and the B-2 wells are drilled to a depth of half the distance between B-1 and B-3. The Group C wells follow the same pattern as the "B" wells. Table 54 summarizes the ranges and average depths of each group of wells.

Table 54. DEPTH OF LAGOON SEEPAGE WELLS

Well group	Average depth, m	Range, m
A	17	13-24
B-1	5	4- 7
B-2	10	7-14
B-3	15	6-26
C-1	5	4- 7
C-2	11	7-14
C-3	17	10-24

Data typical of water quality in the lagoon seepage wells are graphed in Figures 66 and 67. The figures represent Well Group 13 which is located at the southwest corner of the storage lagoon and so was chosen because natural groundwater flow pre-construction was southwesterly.

The results include pre-operations 1973 data and operational 1974-1975 data, showing chloride and nitrate concentrations, two ions which are extremely mobile in most soil horizons. The 1973 samples were taken in March, April, October, and December; in 1974, May and October; and in 1975, in April and August. Throughout the three years, the concentrations remained extremely low: less than 0.5 mg/l for nitrate and less than 10mg/l for chloride.

In well 13-A, the vacillation of chloride, with increases in the spring and decreases for the rest of the year, was attributed to lagoon hydraulic loading. Nitrate nitrogen remained low throughout this period.

In wells 13-B-1 and 13-B-2, there was again a suggestion of direct response to lagoon hydraulic loading but with a general trend toward reduction in chloride. Nitrate showed erratic response.

Well 13-B-3 water closely paralleled that of 13-A.

The outermost group of lagoon seepage wells is profiled in Figure 67 and includes 13-C-1, C-2

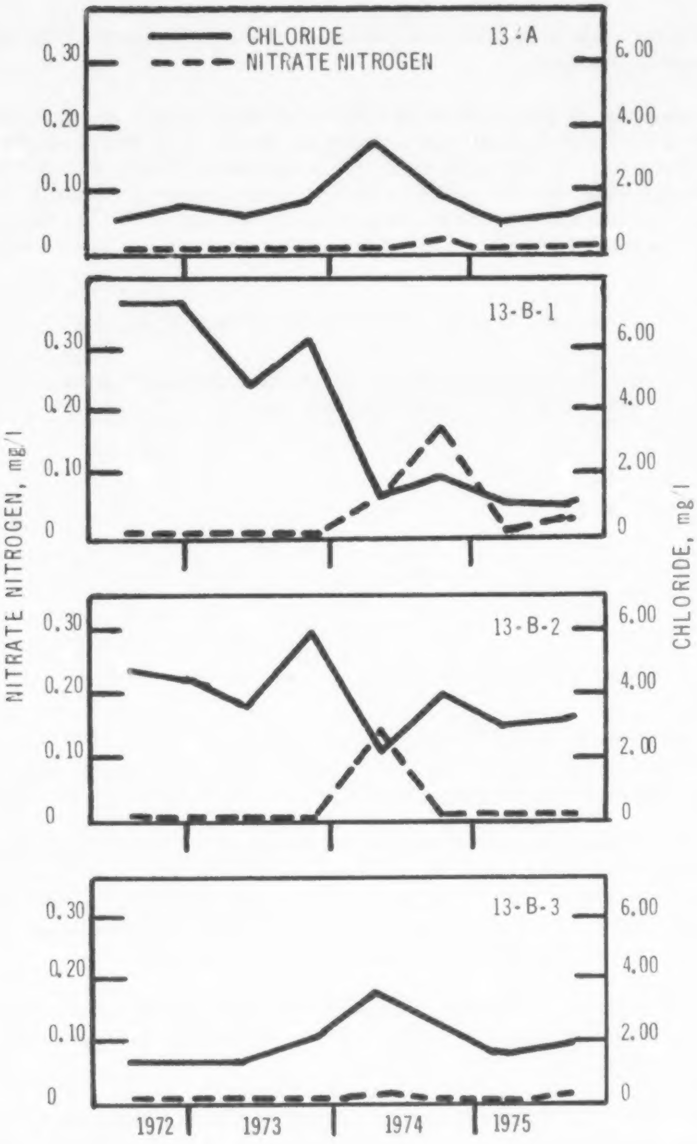

Figure 66. Nitrate nitrogen and chloride in groundwater near storage lagoons, 1972-1975

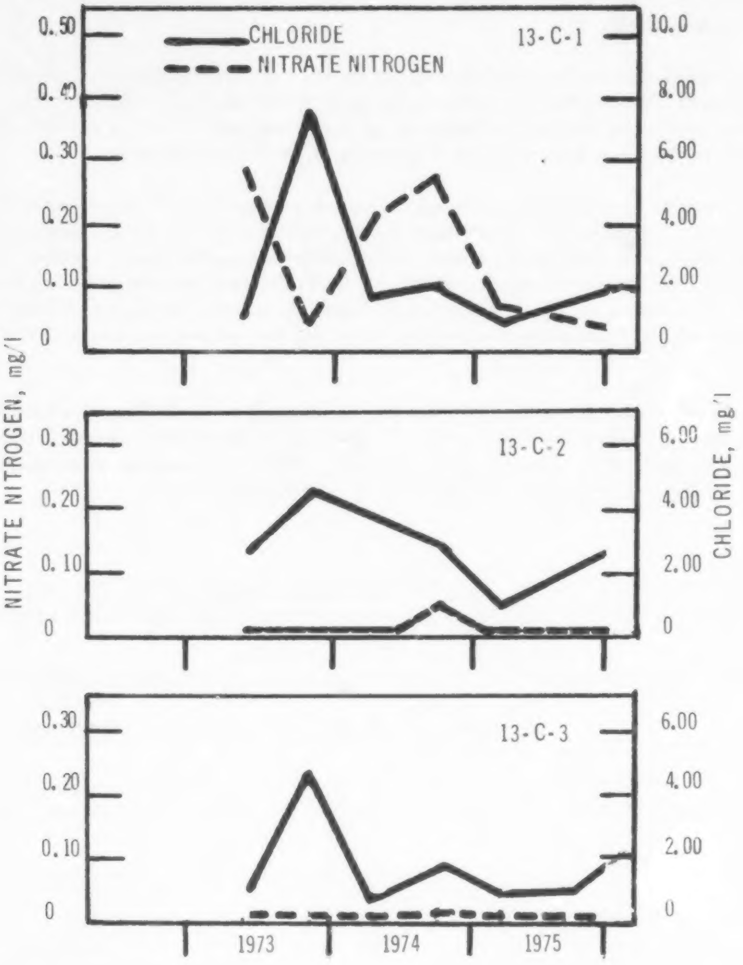

Figure 67. Nitrate nitrogen and chloride in groundwater near storage lagoons, 1973-1975

and C-3. These wells were not yet installed in early 1973, but all other sampling dates were the same as in Figure 66. Except for a matter of degree with regard to chloride, these three wells responded similarly with concentration going up with lagoon hydraulic loading. The nitrate nitrogen levels showed little – if any – response to lagoon operations, and, most often, nitrate levels were nearly undetectable.

It may be concluded that in the case of well group 13, the concentrations of chloride and nitrate from 1973 through 1975 either remained unchanged or tended to steadily decrease. The limited amount of data precluded statistical treatment of these findings, but in order to evaluate possible general trends in the groundwater, a broad grouping of well data was done.

Water quality results on the lagoon seepage wells are presented in three arrangements. The first – a "non-specific" arrangement – tabulates for all wells the means of the parameters measured for the pre-operational period of 1972 and 1973 and for the operational period of 1974-1975. These data in Table 55 should reveal whether significant changes occurred in groundwater after start-up of wastewater operations. Included in Table 55 are the means of nitrate, chloride, phosphate and conductivity, including the range of high and low values, standard deviations and variances.

Pre-operation nitrate nitrogen averaged 0.18 mg/l and doubled to 0.39 mg/l after start-up; in the same time frame, chloride went from 4.8 to 13 mg/l, and conductivity was slightly raised from 2.0 to 2.7 µmhos/cm [x100]. Phosphate was stable. With the exception of chloride, the order of magnitude of these changes was not considered significant.

Table 55. COMPARISONS OF SELECTED WATER PARAMETERS ON ALL LAGOON SEEPAGE WELLS BEFORE AND AFTER WASTEWATER OPERATIONS

Parameter	Year	Average	High	Low	Standard deviation	Variance
NO_3-N, mg/l	1972-1973	0.18	16.4	0[a]	0.91	0.83
	1974-1975	0.39	24.3	0	1.39	1.93
NO_2-N, mg/l	1972-1973	-	-	-	-	-
	1974-1975	0	0.20	0	0.01	0
Chloride, mg/l	1972-1973	4.80	240.	0	16.8	282
	1974-1975	13.0	686	0	38.9	1510
PO_4-P, mg/l	1972-1973	0.03	1.00	0	0.05	0.003
	1974-1975	0.02	1.80	0	0.06	0.003
Conductivity, µmhos/cm[x100]	1972-1973	2.00	11.0	0.20	1.00	1.10
	1974-1975	2.70	22.4	0.30	2.00	4.10

[a] A value of zero indicates not detectable with instrumentation in use.

The "second" data arrangement is by geographical well grouping: west, southwest and south, independent of the distances from the lagoons and the depth of the wells. These data in Table 56 should indicate whether changes occurred in particular locales in the lagoon area.

Nitrate increased in all well locations after starting wastewater operations, with the greatest increase – about threefold – in the south. Chloride also about tripled in concentration after operations in two well groups, the southwest and south, but remained the same in the west. This apparent surge in chloride could be attributed to the history of oil drilling in the area; brackish water in large amounts was associated with the drilling and is expected to be still shifting about in the water table. It should be noted that the increases in chloride levels were most pronounced in the group C wells which are those wells most remote from the lagoons; this was believed to be an indication that the chloride increases could not be attributed to the lagoon impoundment per se. Furthermore, the USGS preliminary findings indicated that the movement of groundwater is *toward* the lagoons, suggesting that if there was intrusion of brackish water toward the lagoon seepage well system, it would first be detected in the C-group. The chloride data in Table 56 are consistent with these expectations. Phosphate remained stable. (Because phosphate was always found to be at the margin of detectability, it was regarded as insignificant and was from this point onward excluded from discussion.) Conductivity findings roughly parallel chloride, with the most increase in the south and southwest well groups. These increases do indicate groundwater movement at the treatment site, but the concentrations were still so low as to be of questionable significance.

The third data arrangement is according to geographic location, distance from lagoon and depth of well. These data in Table 57 should illustrate changes in groundwater quality as a function of groundwater movement from the area of the lagoons.

Nitrate levels showed a tendency toward increasing in concentration after start-up of wastewater operations in all but the deepest batteries of wells, with the highest levels in the shallow wells of the B-1 and C-1 groups, which are subject to fluctuations by changes in groundwater table, rainfall, leaching, etc. Although the intermediate-depth wells showed slight increases, they were considered insignificant, None of the increases were regarded as remarkable.

Chloride increases, as mentioned, were greatest in the wells farthest from the lagoons, the C-group, with the largest concentrations found in the south group, including all depths. Much smaller increases were found at almost all well depths and at almost all distances from the lagoons. A few well groupings in the west and south failed to conform to the general pattern of increases.

Conductivity data roughly paralleled the findings with chloride, with the largest increases being found in the C-group of wells, from 2.5 to 4.1 μmhos/cm [x100]. The western group with two exceptions showed no increases, and the southwest group showed trace or no increases. There seemed to be no trends correlating conductivity and well depth.

Phosphate concentrations were stable and very low. Only averages of phosphate concentrations were included in Table 57 because the numbers were consistantly near zero.

The data in Table 57 indicate that the water quality in the lagoon seepage wells has gradually deteriorated since the beginning of wastewater operations. Nitrate, chloride and conductivity values have increased, particularly in the shallow well groups of the south and southwest that are farthest away from the lagoons. This tendency could be the result of groundwater shifting towards the lagoons, for it is still suspected that some of these alterations in parameters are due to past oil drilling activities in the vicinity of the treatment site.

Table 56. COMPARISONS BEFORE AND AFTER WASTEWATER OPERATIONS OF SELECTED WATER PARAMETERS ON LAGOON SEEPAGE WELLS GROUPED BY LOCATION

Parameter and well locations	Year	Average	High	Low	Standard deviation	Variance
Nitrate, mg/l						
West	1972-1973	0.20	16.4	0[a]	1.00	1.00
	1974-1975	0.40	11.0	0	1.14	1.30
Southwest	1972-1973	0.25	8.30	0	1.03	1.06
	1974-1975	0.34	12.40	0	1.30	1.69
South	1972-1973	0.15	6.00	0	0.76	0.58
	1974-1975	0.43	24.3	0	1.71	2.94
Chloride, mg/l						
West	1972-1973	4.4	193	0	16.5	270
	1974-1975	4.0	168	0	12.1	145
Southwest	1972-1973	3.6	24.0	0.75	3.88	15.0
	1974-1975	9.0	124	0	17.8	318
South	1972-1973	6.8	240	0.40	24.3	592
	1974-1975	24.1	686	0	61.1	3735
Ortho phosphate, mg/l						
West	1972-1973	0.03	0.36	0	0.04	0.001
	1974-1975	0.02	1.77	0	0.09	0.001
Southwest	1972-1973	0.04	0.23	0	0.04	0.001
	1974-1975	0.02	0.13	0	0.02	0.001
South	1972-1973	0.04	0.98	0	0.08	0.006
	1974-1975	0.02	0.10	0	0.02	0
Conductivity, μmhos/cm[x100]						
West	1972-1973	1.70	5.70	0.44	0.61	0.374
	1974-1975	1.90	9.70	0.48	1.03	1.06
Southwest	1972-1973	2.20	4.40	0.48	0.94	0.884
	1974-1975	2.60	6.70	0.50	1.31	1.71
South	1972-1973	2.30	10.9	0.22	1.42	2.01
	1974-1975	3.30	22.4	0.32	2.80	7.86

[a] A value of zero indicates not detectable with instrumentation in use.

Table 57. COMPARISONS BEFORE AND AFTER WASTEWATER OPERATIONS OF NITRATE IN LAGOON SEEPAGE WELLS GROUPED BY DISTANCES FROM LAGOON AND BY DEPTH OF WELL

Well group and year of readings		mg/l											
		Average			High			Low			Standard deviation		
		West	South-west	South	West	South-west	South	West	South-west	South	West	South-west	South
A wells	1972-1973	0.03	0	0	1.34	0.02	0.02	0	0	0	0.20	0	0.01
	1974-1975	0.12	0.03	0.14	3.39	0.18	3.36	0	0	0	0.45	0.05	0.54
B-1 wells	1972-1973	0.70	0.90	0.03	16.4	6.40	0.27	0	0	0	2.47	1.56	0.06
	1974-1975	1.25	0.73	0.45	10.9	4.40	4.75	0	0	0	2.09	1.28	0.89
B-2 wells	1972-1973	0.01	0.24	0	0.30	6.00	0.09	0	0	0	0.04	1.15	0.02
	1974-1975	0.14	0.26	0.05	1.19	5.40	0.60	0	0	0	0.25	1.00	0.13
B-3 wells	1972-1973	0.04	0.04	0	0.58	0.99	0.02	0	0	0	0.11	0.19	0
	1974-1975	0.11	0.03	0.03	1.43	0.43	0.61	0	0	0	0.25	0.07	0.09
C-1 wells	1972-1973	0.35	0.68	1.02	3.52	8.30	5.92	0	0	0	0.75	1.95	1.81
	1974-1975	0.66	1.27	1.92	7.36	12.4	24.3	0	0	0	1.54	2.85	3.74
C-2 wells	1972-1973	0.02	0	0.01	0.23	0.06	0.09	0	0	0	0.04	0.01	0.02
	1974-1975	0.36	0.09	0.12	5.00	1.64	2.90	0	0	0	1.04	0.26	0.42
C-3 wells	1972-1973	0.01	0	0	0.12	0.01	0.02	0	0	0	0.02	0	0
	1974-1975	0.05	0.01	0.05	0.80	0.06	1.02	0	0	0	0.12	0.02	0.16

Table 57 (continued). COMPARISONS BEFORE AND AFTER WASTEWATER OPERATIONS OF CHLORIDE IN LAGOON SEEPAGE WELLS GROUPED BY DISTANCES FROM LAGOON AND BY DEPTH OF WELL

Well group and year of readings		mg/l											
		Average			High			Low			Standard deviation		
		West	South-west	South	West	South-west	South	West	South-west	South	West	South-west	South
A wells	1972-1973	2.31	1.49	1.29	22.1	2.50	2.09	0.00	1.05	0.80	4.24	0.38	0.39
	1974-1975	6.49	3.32	1.77	96.0	43.5	10.0	0	0	0	18.0	8.06	1.69
B-1 wells	1972-1973	1.60	2.78	2.50	10.0	10.2	10.8	0.07	1.10	0.65	1.57	2.39	2.63
	1974-1975	3.18	8.85	2.39	59.0	57.6	31.0	0	0	0	8.51	16.7	4.93
B-2 wells	1972-1973	2.85	5.23	2.49	43.0	18.9	11.7	0.63	0.75	0.70	6.23	4.23	2.77
	1974-1975	4.18	14.2	3.96	33.0	90.0	83.0	0	1.00	0	6.17	23.2	13.0
B-3 wells	1972-1973	2.39	2.77	1.41	20.2	24.0	3.38	0.38	0.83	0.80	3.50	4.34	0.57
	1974-1975	2.16	5.40	2.54	18.0	51.0	16.0	0	0.60	0	2.94	10.7	3.07
C-1 wells	1972-1973	9.06	5.55	18.3	185	14.7	192	0.55	0.93	2.74	28.5	4.10	35.2
	1974-1975	1.96	12.1	58.5	16.0	124	225	0	1.00	0.80	2.78	21.8	67.4
C-2 wells	1972-1973	10.6	5.59	17.6	193	17.9	240	0.10	1.21	0.80	31.2	4.18	48.5
	1974-1975	4.0	11.0	53.4	24.0	78.0	686	0	0.90	1.40	5.97	17.7	114
C-3 wells	1972-1973	2.07	2.63	2.39	9.50	21.5	22.4	0	0.89	0.40	2.15	4.01	4.38
	1974-1975	5.80	7.32	24.0	168	100	248	0	0.70	0	24.1	19.6	44.0

Table 57 (continued). COMPARISONS BEFORE AND AFTER WASTEWATER OPERATIONS OF CONDUCTIVITY IN LAGOON SEEPAGE WELLS GROUPED BY DISTANCES FROM LAGOON AND BY DEPTH OF WELL

Well group and year of readings		μmhos/cm[x100]											
		Average			High			Low			Standard deviation		
		West	South-west	South	West	South-west	South	West	South-west	South	West	South-west	South
A wells	1972-1973	1.76	2.87	2.75	2.54	4.11	4.52	1.10	2.34	1.75	0.33	0.45	0.81
	1974-1975	2.15	3.37	3.71	8.04	6.25	6.13	1.27	1.86	1.81	1.32	0.82	1.19
B-1 wells	1972-1973	1.29	1.28	1.87	2.98	2.95	10.9	0.62	0.70	0.44	0.50	0.58	2.17
	1974-1975	2.00	1.54	2.35	7.19	5.03	19.1	0.48	0.50	0.32	1.70	1.33	3.96
B-2 wells	1972-1973	1.81	2.35	2.02	2.78	3.84	3.66	1.11	1.37	0.93	0.35	0.60	0.77
	1974-1975	1.97	3.01	2.54	3.22	6.65	14.4	1.04	1.34	1.24	0.48	1.51	2.80
B-3 wells	1972-1973	1.89	2.64	2.20	2.68	4.01	4.07	1.07	1.90	0.23	0.38	0.44	0.60
	1974-1975	1.91	3.10	2.90	3.41	6.70	16.7	1.18	1.68	1.45	0.43	0.97	2.70
C-1 wells	1972-1973	1.58	0.91	2.23	4.84	1.81	8.70	0.44	0.48	0.61	0.91	0.37	2.01
	1974-1975	1.53	1.63	3.77	9.70	5.90	13.6	0.48	0.51	0.55	1.28	1.14	3.28
C-2 wells	1972-1973	1.89	2,10	2.54	5.74	2.88	9.45	0.94	1.46	1.07	0.93	0.34	1.59
	1974-1975	1.79	2.42	4.08	3.38	4.13	22.4	0.83	1.20	1.18	0.51	0.61	3.12
C-3 wells	1972-1973	1.82	3.26	2.77	2.74	4.43	4.99	1.02	1.85	0.22	0.40	0.92	0.93
	1974-1975	1.88	3.38	3.38	3.37	5.92	8.17	1.13	1.63	1.61	0.50	1.15	1.38

Table 57 (continued) COMPARISONS BEFORE AND AFTER WASTEWATER OPERATIONS OF PHOSPHATES IN LAGOON SEEPAGE WELLS GROUPED BY DISTANCES FROM LAGOON AND BY DEPTH OF WELL

Well group and year		Average, mg/l		
		West	Southwest	South
A wells	1972-1973	0.02	0.03	0.08
	1974-1975	0.02	0.01	0.02
B-1 wells	1972-1973	0.03	0.04	0.01
	1974-1975	0.02	0.02	0.01
B-2 wells	1972-1973	0.02	0.03	0.03
	1974-1975	0.02	0.01	0.02
B-3 wells	1972-1073	0.03	0.03	0.03
	1974-1975	0.02	0.01	0.02
C-1 wells	1972-1973	0.03	0.04	0.02
	1974-1975	0.02	0.01	0.01
C-1 wells	1972-1973	0.02	0.04	0.05
	1074-1975	0.02	0.02	0.01
C-3 wells	1972-1973	0.02	0.04	0.04
	1974-1975	0.06	0.02	0.02

Perimeter Wells –

The most common arrangement of the perimeter wells is a cluster of three wells less than a meter apart with depth patterns similar to the lagoon seepage wells. See Figure 65. The perimeter well water was tested for BOD_5, TOC, color, conductivity, chloride, nitrate and phosphate.

Table 58. DEPTH OF PERIMETER WELLS

Well No.	Average depth, m	Range, m
1	5	4- 7
2	10	6-13
3	15	9-16

The data presentation in Table 59 is by depth groupings which allows comparison of groundwater quality before and after operations as well as possible assessment of groundwater movements near the site boundaries. All averages represent groupings of wells of the same depth.

No significant changes occurred in color, conductivity, phosphate and BOD_5 at any of the well depths. TOC and chloride concentrations decreased at all well depths. Nitrate decreased in shallow wells and increased slightly with depth.

Interpretation of the perimeter well results is very difficult. The standard deviations for almost all parameters are extraordinarily high. Some of the parameters may have been caused by the intrusion of extraneous factors outside of WMS control. For instance, some wells were originally drilled in roadside ditches where winter salt runoff could infiltrate. Other wells were put in areas with a history of oil drilling and therefore with possible pockets of concentrated saline. On the northern site boundry, many of the wells went dry, but those still functional showed either no change or slight decreases for most parameters.

Surface Water

The two major surface water systems receiving effluent from the project are the Mosquito Creek - Muskegon Lake system and the Big Black Creek - Mona Lake system; these are illustrated in Figure 17.

To establish background water quality (or "pre-operations" quality), sampling of surface waters was begun in 1972 with monthly samples through 1973. During 1974-1975 sampling was quarterly.

Samples from the lakes were taken from boats; from shallow streams, samples were taken from bridges or from midstream by wading in.

Surface Water Monitoring Results –

Phosphate phosphorus and ammonia nitrogen in Mona Lake are plotted in Figures 68, 69 and 70 from 1972-1975. Phosphorus levels over that period of time dropped from about 0.46 ppm to about 0.06 ppm. In the case of ammonia nitrogen, analyses were not begun until June, 1974, and from that date through 1975 there was no apparent trend to the data. It is believed that the dramatic increase in nitrogen in the fall of 1975 was the result of lake-bottom mixing which

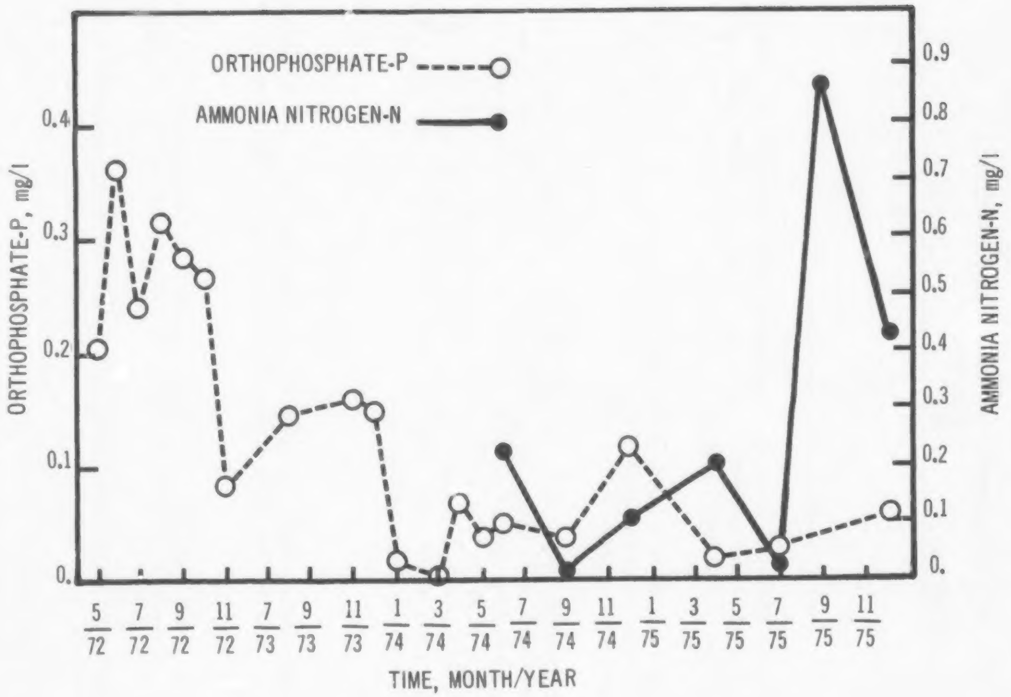

Figure 68. Concentrations of Orthophosphate-P and Ammonia Nitrogen-N in Mona Lake, East End, 1972-1975

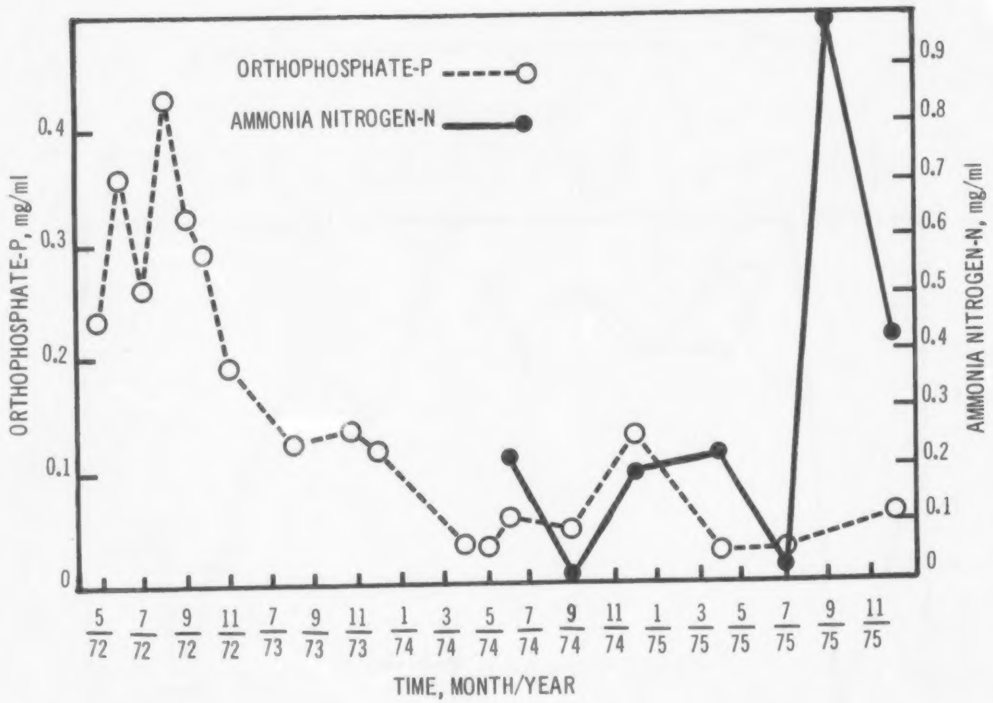

Figure 69. Concentrations of Orthophosphate-P and Ammonia Nitrogen-N in Mona Lake, Middle Region, 1972-1975

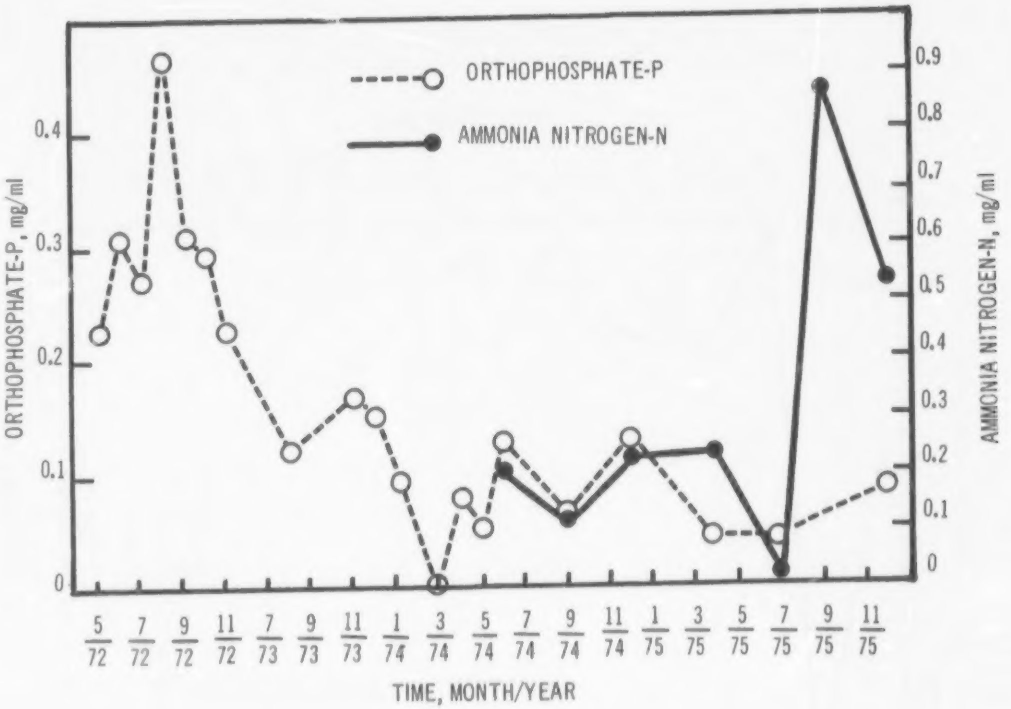

Figure 70. Concentrations of Orthophosphate-P and Ammonia Nitrogen-N in Mona Lake, West End, 1972-1975

Table 59. COMPARISONS BEFORE AND AFTER WASTEWATER OPERATIONS OF SELECTED PARAMETERS IN PERIMETER WELLS GROUPED BY WELL DEPTH

Parameter and year		Average			High			Low			Standard deviation		
		5m	10m	15m	5m	10m	15m	5m	10m	15m	5m	10m	15m
Color, APHA	1972-1973	45.5	59.3	53.5	120	175	210	5.0	5.0	5.0	27.2	35.8	31.9
	1974-1975	46.3	59.5	69.2	250	350	325	5.0	5.0	5.0	40.9	52.0	62.9
Conductivity, μmhos/cm[x100]	1972-1973	4.9	5.6	3.6	12.6	15.7	7.7	1.0	1.1	1.1	2.6	4.1	1.7
	1974-1975	4.7	4.5	3.7	5.9	19.8	12.1	1.1	1.1	1.2	2.8	3.6	1.9
TOC, mg/l	1972-1973	24.7	21.9	17.6	62.5	57.5	55.0	3.1	2.4	2.5	20.9	19.0	16.3
	1974-1975	7.3	7.8	9.0	40.7	37.0	75.0	1.0	1.0	0.3	4.8	5.5	8.3
Chloride, mg/l	1972-1973	87.1	101	30.2	340	361	166	0.6	0.1	0.6	90.0	127	42.7
	1974-1975	54.6	58.6	24.8	395	444	310	0	0	0	69.3	110	51.6
PO_4-P, mg/l	1972-1973	0.12	0.02	0.04	1.2	0.08	1.8	0	0	0	0.28	0.01	0.12
	1974-1975	0.10	0.02	0.04	12.3	0.77	1.5	0	0	0	0.86	0.05	0.16
NO_3-N mg/l	1972-1973	1.2	0.1	0.1	12.8	3.8	5.9	0	0	0	2.7	0.5	0.7
	1974-1975	0.7	0.6	0.3	13.6	9.9	10.9	0	0	0	1.6	1.8	1.2
BOD_5, mg/l	1972-1973	0.6	0.7	0.9	1.6	3.0	4.7	0.1	0	0	0.4	0.6	1.0
	1974-1975	0.7	0.7	1.1	0.2	9.8	6.0	0	0	0	0.9	1.0	1.3

occurs when the lake undergoes inversion. Phosphate increases during this period – though small – were probably also related to inversion.

Muskegon Lake results for PO_4-P and NH_4-N over the same time period are depicted in Figures 71, 72 and 73. Phosphorus concentrations decreased only slightly from 1972-1975. This difference in phosphorus behavior between Mona and Muskegon Lakes was attributed to a corresponding difference in the mean hydraulic retention times of the two lakes: for Muskegon Lake, 23 days, and for Mona Lake, 76 days.[11] The relatively short retention time of Muskegon Lake in combination with the relatively infrequency of sampling – either once per month or quarterly – create a strong likelihood that the increased levels of phosphorus which are known to occur during spring and fall inversions were simply not detected. But it should be emphasized that the 1972 phosphorus levels in Muskegon Lake were less than 0.1 ppm; this concentration is already low, and any trend toward further decrease would be less spectacular than in Mona Lake.

Ammonia nitrogen in Muskegon Lake followed no apparent trend. Those increases which did occur were significantly less than in Mona Lake, for reasons already cited.

Ammonia nitrogen, phosphate phosphorus, dissolved oxygen, BOD_5, color, conductivity and chloride data from 1972-1975 are presented in Table 60. for the major component waterways of the two watersheds.

The Lakes – In both lakes the dissolved oxygen concentration increased about 20 percent from 1972 to 1975, and BOD decreased significantly. Nitrate nitrogen increased in both lakes – from 0.34 to 0.64 ppm in Mona and from 0.1 to 0.2 ppm in Muskegon – but these levels are regarded as very low. In the cases of chloride, conductivity and color, the changes were so small as to be considered insignificant. Generally, the WMS analyses over the reporting period show some improvement in water quality of Mona and Muskegon Lakes.

These lakes have been under study by investigators from the University of Michigan. Their findings were reported in the Applicability of Land Treatment of Wastewater in the Great Lakes Basin by Paul Freedman, *et. al.*, Muskegon County Wastewater Treatment Study Project, EPA Grant No. G 005104; August, 1976.

The period during which these lakes were evaluated – about two years – is brief in terms of expecting to detect major changes in bodies of water of this size. However, the monitoring of the lakes was ongoing after 1975, and findings are expected to be reported by 1978.

The Creeks – Except for nitrate nitrogen which doubled from 0.3 to 0.6 ppm, there were no significant changes in the parameters measured in Mosquito Creek.

In Big Black Creek, chloride levels decreased. There were no other significant changes in the parameters measured.

In Figure 74, results for Mosquito Creek and nitrate nitrogen are plotted for 1972-1975, with the two lines representing samples taken upstream from the project outfall and downstream from the outfall. In the cases of BOD_5 and ammonia nitrogen, no significant differences were found in samples above and below the outfall. With nitrate nitrogen, levels show some seasonal response, and in mid 1975 the concentration dramatically increased below the outfall. It was suspected that this high nitrate may have been due to nitrogen leaching following the spring thaw and the first irrigation season. Overall, the data on stream water quality indicated that, over the reporting period, the discharge of treated effluent from the WMS site had no significant effect on the receiving streams.

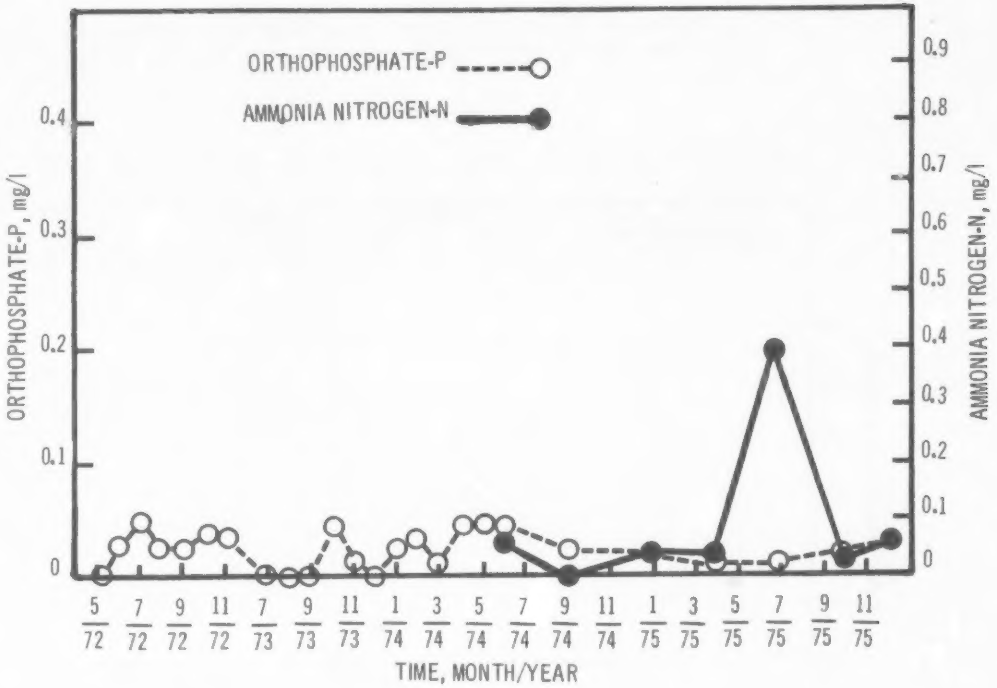

Figure 71. Concentrations of Orthophosphate-P and Ammonia Nitrogen-N in Muskegon Lake, East End, 1972-1975

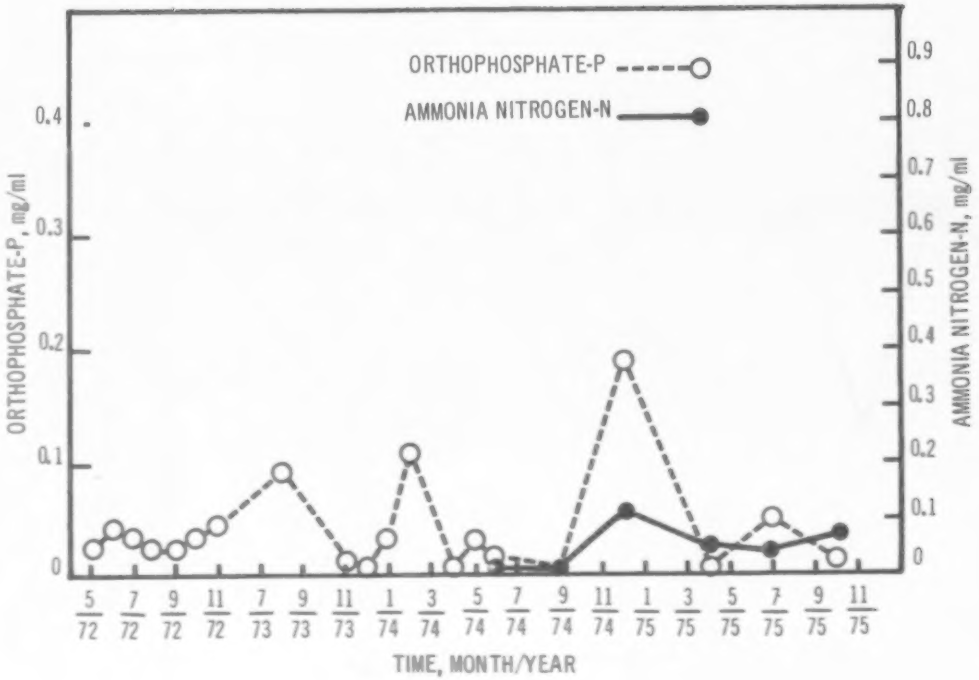

Figure 72. Concentrations of Orthophosphate-P and Ammonia Nitrogen-N in Muskegon Lake, West End (South), 1972-1975

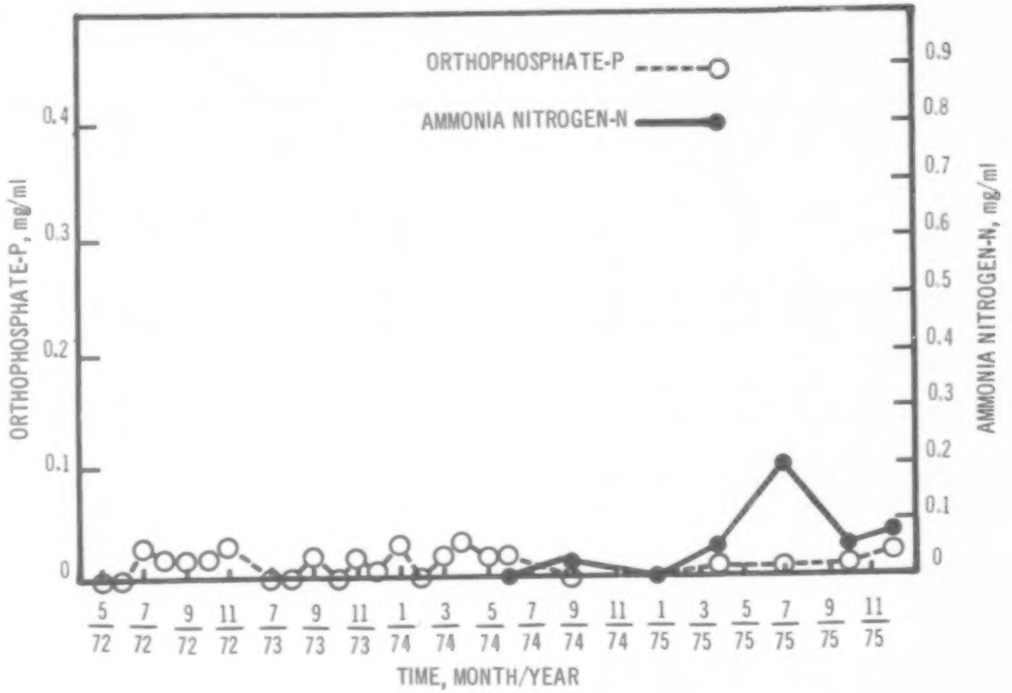

Figure 73. Concentrations of Orthophosphate-P and Ammonia Nitrogen-N in Muskegon Lake, West End (North), 1972-1975

Table 60. COMPARISONS BEFORE AND AFTER WASTEWATER OPERATIONS OF SELECTED PARAMETERS IN MAJOR SURFACE WATERS SYSTEMS GROUPED BY WATERSHED

		Mosquito Creek				Muskegon Lake				Big Black Creek				Mona Lake			
Parameter	Year	Ave	High	Low	SD	Ave	High	Low	SD	Ave	High	Low	SD	Ave	High	Low	SD
Dissolved Oxygen, mg/l	1972-1973	9.9	13.0	6.6	1.4	9.6	14.4	6.0	1.8	8.9	12.6	5.6	1.7	10.9	17.8	6.9	3.0
	1974-1975	10.4	13.2	5.9	2.3	11.6	14.4	6.8	1.9	8.7	12.9	1.9	2.5	12.3	18.1	4.3	2.8
BOD_5, mg/l	1972-1973	1.7	4.0	0.1	1.0	3.4	13.0	1.4	2.1	2.3	6.2	0.1	1.7	4.9	9.5	2.0	1.7
	1974-1975	1.9	4.0	0.7	0.9	2.8	5.9	1.2	0.9	2.0	3.9	0.7	0.8	3.8	7.5	1.2	1.3
Color, APHA	1972-1973	68.0	120.0	15.0	24.7	42.0	100.0	20.0	17.7	78.0	125.0	40.0	25.6	54.0	120.0	10.0	22.3
	1974-1975	87.0	400.0	20.0	66.1	40.0	120.0	10.0	19.3	89.0	250.0	30.0	39.3	56.0	100.0	20.0	35.2
Conductivity, μmhos/cm [x100]	1972-1973	2.6	5.6	1.7	0.9	3.0	3.8	2.0	0.4	3.9	6.4	2.5	1.0	4.1	5.4	2.2	0.8
	1974-1975	3.3	7.1	1.8	1.5	3.2	5.0	2.0	0.7	4.0	9.0	1.2	1.3	4.2	7.6	2.0	1.2
Chloride, mg/l	1972-1973	9.6	170.0	2.2	26.0	23.7	68.0	16.6	10.8	26.6	63.4	9.7	16.4	53.4	213.0	7.5	39.9
	1974-1975	16.1	70.2	0.4	21.4	22.0	80.5	12.3	10.3	13.2	49.0	3.0	10.6	43.2	93.0	11.5	18.8
NO_3-N, mg/l	1972-1973	0.3	0.5	0.1	0.1	0.1	0.4	0	0.1	0.6	1.2	0.1	0.3	0.3	1.2	0	0.4
	1974-1975	0.6	3.8	0.1	0.7	0.2	0.5	0	0.2	0.6	2.8	0	0.5	0.6	1.2	0	0.4
PO_4-P, mg/l	1972-1973	0	0.1	0	0	0	0.1	0	0	0	0.1	0	0	0.2	0.5	0	0.1
	1974-1975	0	0.1	0	0	0	0.2	0	0	0	0.2	0	0	0.1	0.2	0	0.1

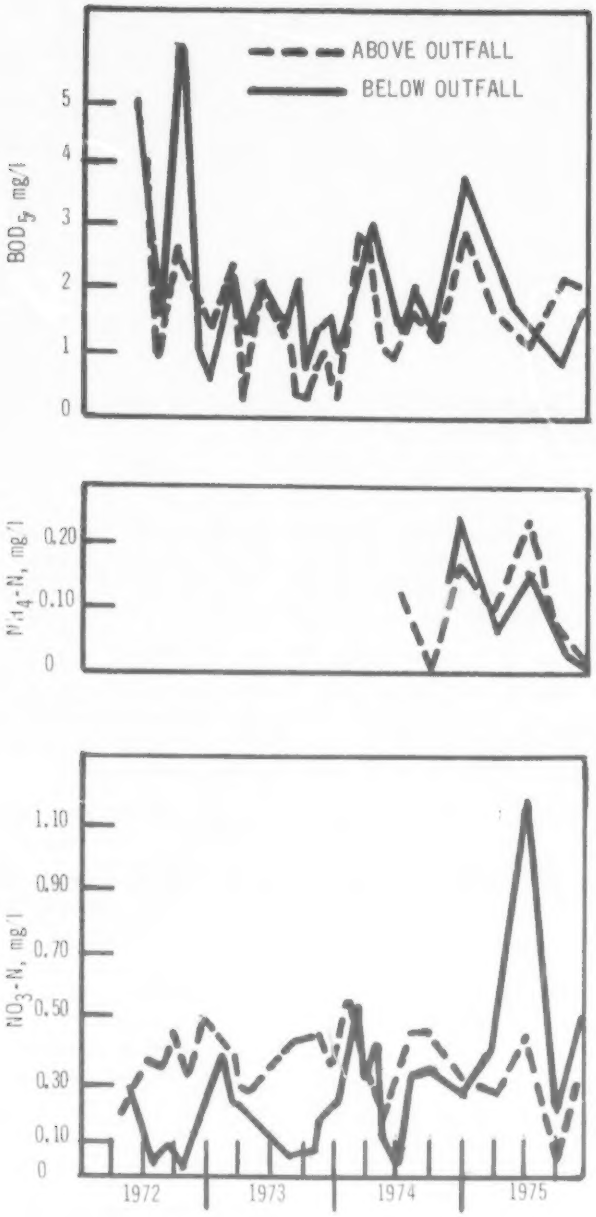

Figure 74. Five-day biochemical oxygen demand, ammonia nitrogen and nitrate nitrogen above and below WMS discharge outfall

SECTION 9

WATER AND MATERIALS BALANCE

An important consideration in the evaluation of a wastewater treatment system is an accounting of incoming and outgoing materials.

WATER BALANCE

Water balance calculations were based on the following measurements: continuous recordings of influent volume and rainfall, pump-hour readings recorded by meters, and an estimate of lagoon evaporation derived from the lagoon design model. (See Appendix E for the detail on the lagoon model). Drainage well volumes were estimated based on hours of service, when appropriate.

Table 61 lists those factors which have a role in the water balance of the storage lagoons. According to these 1975 data, the total volume of water received into storage – including rainfall – was 50,081 TCM, and the total volume discharged, including through evaporation, was 60,514 TCM, a difference of 10,433 TCM. It was believed this amount might be attributable to either intrusion of groundwater or to small errors in estimations or both.

Table 61. STORAGE LAGOON WATER BALANCE, 1975

Total lagoon water from:	In, TCM	Total lagoon water to:	Out, TCM
[Level adjustment]	2,884	Irrigation	28,152
Influent	35,511	Direct spill	6,382
Precipitation	5,705	Evaporation	3,642
Ensley pumping	102	Ensley pumping	9,899
Sullivan pumping	5,879	Sullivan pumping	12,439
Total	50,081	Total	60,514
		Less water in	50,081
		Net difference from groundwater	10,433

Methods of Measurement for Table 61 Parameters

"Level adjustment" refers to a method of compensating for differences in lagoon elevation on January 1 of each year. For instance, from 1/1/75 to 1/1/76, the elevation of the east lagoon was the same, and no adjustment was necessary. But in the case of the west lagoon, about 3,000 TCM "extra" was discharged during the year of 1975.

Date	West lagoon level
January 1, 1975	208.7 meters
January 1, 1976	207.8 meters
	0.9 x 3,204 TCM/ft = 2,884 TCM

This volume represents carry-over from 1974.

"Influent" in Table 61 represents all raw wastewater received from the collection system. Volumes were measured by a sharp-crested rectangular weir and were recorded continuously.

"Precipitation", the total rain and snow for the year, was measured with a weekly recording rain gauge on the site. It was assumed that gauge readings were representative for the entire treatment area.

"Ensley pumping" is a station along the interception ditch on the lagoon north perimeter which can pump either into the lagoon or into the north outfall. Pumping volumes were determined by pump running times as recorded on meters, and rates were derived from curves provided by the manufacturers.

"Sullivan pumping" is a station along the interception ditch on the lagoon south perimeter which can pump either into the lagoon or into surface waters. Pumping volumes and rates were determined as at Ensley.

"Irrigation," the total water irrigated in 1975, was determined by metered pump running times and specific pump curves for each irrigation pumping station.

"Direct spill" is the amount of water, which during January-February, 1975, was discharged directly to Mosquito Creek via the drainage canals, an action necessary to provide adequate storage volume for influent. The volume of direct spill was determined by relating discharge volume to the water depth in the outlet lagoon and to the size of the gate opening from the outlet lagoon.

"Evaporation," the amount of water converted to vapor during the year, was calculated from data on average daily temperatures and seasonal atmospheric constants, using the equation:

$$E = 0.013 F (T_{avg} - 32)$$

where

E = evaporation (inches)

F = seasonal atmospheric constant

T_{avg} = average daily temperatures. (°F)

This equation, the temperature data and the constants, Table 62 below, are from the engineering feasibility study by Bauer Engineering, Inc.

According to the Bauer simulation model, for months during which the average daily temperature was less than 32°F, evaporation may be assumed to be zero.

Table 62. MUSKEGON COUNTY SEASONAL ATMOSPHERIC CONSTANTS (F)

Month	Constant (F)
January-February	0.101
March-April	0.200
May-June	0.298
July-August	0.294
September-October	0.194
November-December	0.124

Total discharge water volume from the site for 1975 is listed in Table 63.

Table 63. SITE DISCHARGE WATER VOLUMES, 1975

Location	Volume TCM	Location	Volume TCM
Mosquito Creek		Black Creek	
Drain pipes	18,825	Drain pipes of Laketon pump station	6,447
Wells in circles 1 & 2 (est)	189	Wells of circles 36, 37, 39, 40 (est)	378
Ensley pump station	9,797	Sullivan pump station	6,560
Direct spill	6,382		
North undrained area	4,735		
Sub-total	39,928	Sub-total	13,385
Total (all locations)	53,313		

By comparing Tables 61 and 63 it can be shown that the difference between the net discharge volume from storage minus evaporation [60,514-(102+5,879)-3,642=50,891 TCM] and the total discharge at the creek outfalls (53,313 TCM) was 2,422 TCM. The additional water that was discharged was attributed to groundwater infiltration into the system.

Methods of Measurement for Table 63 Parameters

Mosquito Creek volumes were recorded from the USGS gauging station on the main drainage canal northeast of circles 1 and 2.

Ensley pump station volumes pumped to the main drainage canal were determined from recorded pump running times.

Wells located south of circles 1 and 2 discharged into the main drainage canal volumes which were estimates based on 100 days pumping at one well at a rate of 1.89 TCMD.

Drain pipe volume was determined by calculating the difference between the measured total volume at the USGS gauging station and the Ensley volume plus the wells and the direct discharge volumes. It was assumed that this difference was contributed solely by the drainage pipes. It was also assumed that the origin of drain pipe water was irrigation alone, that is, evaporation was presumed to equal precipitation.

Because of the steep gradient to Mosquito Creek along sections of the northern boundary, several of the irrigation circles were not provided with drainage pipes. It was assumed, therefore, that some of the irrigation water applied to these circles percolates directly to the creek. The water volume was determined by estimating the percentage of the irrigation circle that was not drained, and this percentage was applied to the total volume irrigated on the circle. The estimates of these volumes are listed in Table 64.

Table 64. VOLUMES OF DRAINAGE WATER TO MOSQUITO CREEK FROM IRRIGATION CIRCLES WITH INCOMPLETE DRAIN PIPE SYSTEM, 1975

Circle number	Percent Area not drained	Estimate volume directly drained, TCM
1	100	1128
2	75	791
4	100	602
5	67	337
8	75	867
9	75	367
14	50	526
15	33	117
	Total	4735 TCM

Black Creek drain pipe volumes included the volume drained from circles 41 to 52 south of Apple Avenue which empty into the Laketon drainage ditch. The Laketon station pumps this water into Black Creek, and volumes were taken from recorded pumping operations and from manufacturers specifications.

Black Creek wells in Table 63 represent the drainage volume from circles 36, 37, 39 and 40. Because these circles were equipped with wells, no drainage pipes were installed; the wells are equipped with pumps and are linked to Black Creek by a pipeline. The volume was estimated based on 50 days pumping of four wells at a rate of 1.89 TCMD.

Sullivan pump station on the south interception ditch discharges to Black Creek. Volumes were determined by pump running time and manufacturer's delivery specifications.

A depiction of the overall water balance at WMS is presented in the form of a flow diagram in Figure 75 which displays many of the interrelationships of the data in Tables 61, 63 and 64.

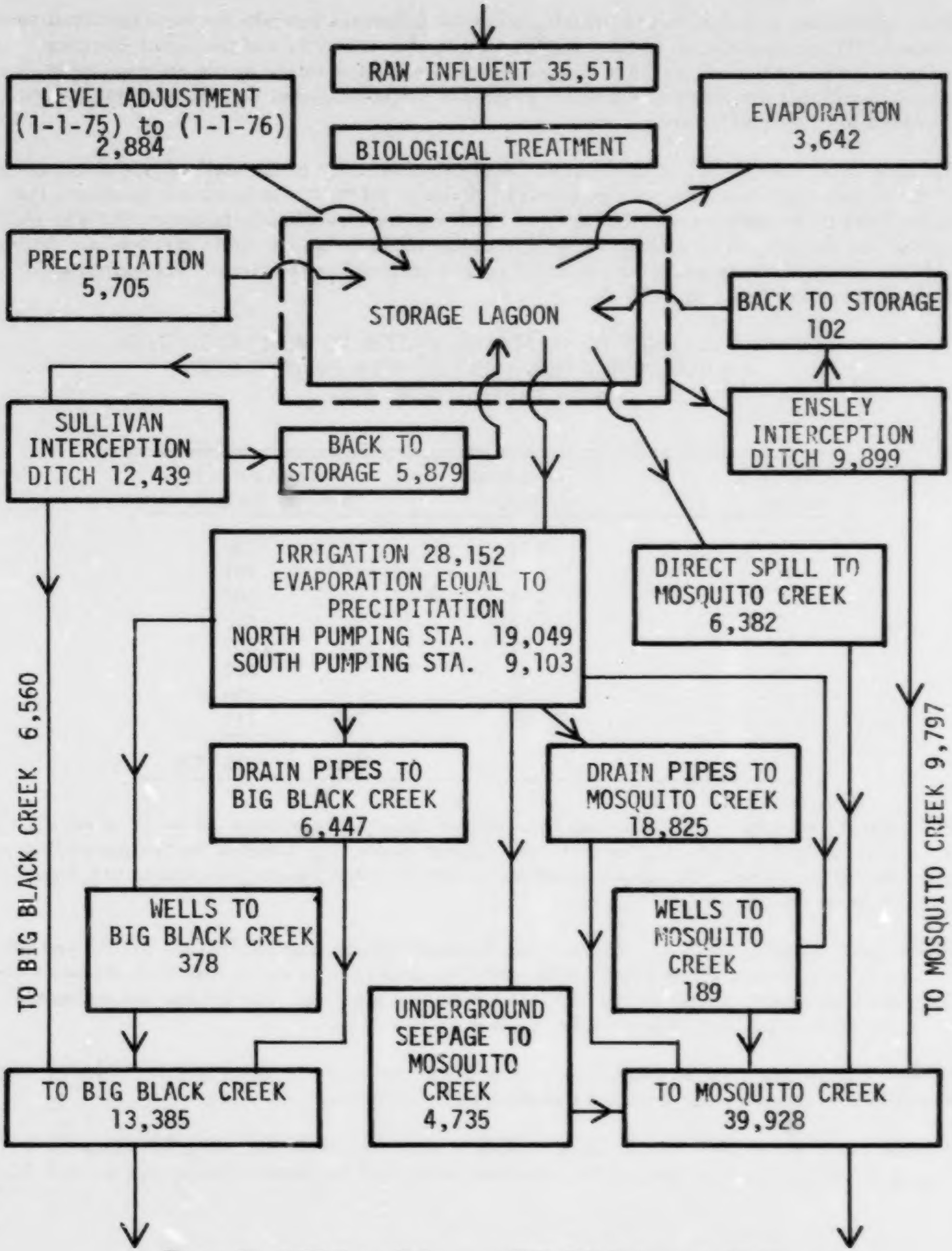
RAW INFLUENT 35,511
BIOLOGICAL TREATMENT
LEVEL ADJUSTMENT (1-1-75) to (1-1-76) 2,884
EVAPORATION 3,642
PRECIPITATION 5,705
STORAGE LAGOON
BACK TO STORAGE 102
SULLIVAN INTERCEPTION DITCH 12,439
BACK TO STORAGE 5,879
ENSLEY INTERCEPTION DITCH 9,899
IRRIGATION 28,152
EVAPORATION EQUAL TO PRECIPITATION
NORTH PUMPING STA. 19,049
SOUTH PUMPING STA. 9,103
DIRECT SPILL TO MOSQUITO CREEK 6,382
TO BIG BLACK CREEK 6,560
TO MOSQUITO CREEK 9,797
DRAIN PIPES TO BIG BLACK CREEK 6,447
DRAIN PIPES TO MOSQUITO CREEK 18,825
WELLS TO BIG BLACK CREEK 378
WELLS TO MOSQUITO CREEK 189
UNDERGROUND SEEPAGE TO MOSQUITO CREEK 4,735
TO BIG BLACK CREEK 13,385
TO MOSQUITO CREEK 39,928

Figure 75. 1975 Water Balance at WMS (All Volumes in TCM)

MATERIAL BALANCE

Biological Treatment Cells and Lagoons

The amounts of materials were calculated from yearly averages of measured wastewater flow rates in Appendix B, Table 1 and the yearly average concentrations in Table 53.

Table 65 contains a listing of the calculated amounts of six important parameters going into and out of the biological treatment cells.

Table 65. KILOGRAMS OF MATERIALS IN WASTEWATER BEFORE AND AFTER BIOLOGICAL TREATMENT, 1975

Parameter	BOD_5	SS	N	P	K	Cl
Influent	7.28×10^6	8.84×10^6	2.93×10^5	8.45×10^4	3.73×10^5	6.46×10^6
Effluent from biological treatment	2.89×10^6	5.12×10^6	3.15×10^5	9.41×10^4	8.67×10^5	6.28×10^6

Whereas BOD_5 and suspended solids showed significant decreases after biological treatment, there were apparent increases in the amounts of nutrients. These increases were probably artifactual. The data were obtained by analysis of grab samples taken only during the day because 24-hour composite samples were not available. More recent analyses of samples taken in 24-hour studies indicated that the highest nutrient loading occurred during the evening hours, probably due to the 10 to 12 hour detention period in the collection network. The biological treatment cells, however, had a 1.5 day detention period with effective mixing, and these data probably more accurately indicated the actual nutrient levels.

After biological treatment 60 percent of the wastewater BOD was satisfied. In the storage lagoons, 91 percent of the biological oxygen demand was met, and suspended solids were by that stage reduced 89 percent. Changes in nutrient concentrations were minor through these two steps of treatment.

Irrigation and Discharge

The amounts of materials applied through irrigation and the corresponding amounts discharged into surface streams are in Table 66.

Table 66. WMS MATERIALS BALANCE FOR SELECTED PARAMETERS, 1975

	BOD_5	Nitrogen	Phosphorus	Potassium	Chloride
Materials *in*, kg					
Applied to field					
From storage to field	3.62×10^{5}	1.59×10^{5}	4.04×10^{4}	2.44×10^{5}	4.32×10^{6}
Fertilizer added	0	1.00×10^{5}	0	0	0
Total applied to field	3.62×10^{5}	2.59×10^{5}	4.04×10^{4}	2.44×10^{5}	4.32×10^{6}
Materials *out*, kg					
Out through drain pipes					
To Mosquito Creek	2.21×10^{4}	4.76×10^{4}	2.35×10^{2}	5.02×10^{4}	1.14×10^{6}
To Big Black Creek	1.48×10^{4}	9.86×10^{3}	1.29×10^{2}	1.78×10^{4}	2.06×10^{5}
Out through wells					
To Mosquito Creek	2.22×10^{2}	4.78×10^{2}	2.36×10^{0}	5.04×10^{2}	1.14×10^{4}
To Big Black Creek	8.69×10^{2}	5.78×10^{2}	7.56×10^{0}	1.04×10^{3}	1.21×10^{4}
Out through seepage (undrained area North)					
To Mosquito Creek	5.56×10^{3}	1.20×10^{4}	5.92×10^{1}	1.26×10^{4}	2.86×10^{5}
Total materials out	4.36×10^{4}	7.05×10^{4}	4.33×10^{2}	8.21×10^{4}	1.66×10^{6}
Kilograms removed, kg	3.18×10^{5}	1.89×10^{5}	4.00×10^{4}	1.62×10^{5}	2.66×10^{6}
Percent removed by land treatment[a]		73.0%	99.0%	66.4%	61.1%
Crop uptake, kg					
Total uptake by grain, kg		1.10×10^{5}	1.96×10^{4}	2.69×10^{4}	—
Total back into soil with stover[a]		8.21×10^{4}	1.35×10^{4}	9.80×10^{4}	—
Total, kg		1.92×10^{5}	3.31×10^{4}	1.25×10^{5}	—
Balance not accounted for, kg		-3.00×10^{3}	$+6.90 \times 10^{3}$	$+3.70 \times 10^{4}$	—

---

[a] Apparent removal by soil and crop

Derivation of Data in Table 66 –

For the category "storage lagoons to field," data were used from Tables 53 and 61. "Nitrogen applied" represents the sum of the total Kjeldahl nitrogen and nitrate nitrogen. For the category "out through drain pipes to Mosquito Creek," values represent averages of all of the drain pipe results in Table 53 and the flow rates from Table 63. It was assumed that the drain pipe results thus averaged were typical because they represent drainage from all of the major soil types. "Nitrogen" here represents the sum of nitrate and ammonia nitrogen. Similarly, these values were used for both the "out through wells" and "out through seepage" categories.

For the category "out through drain pipes to Big Black Creek," data were taken from Big Black Creek findings in Table 53 and flow rates from Table 63. "Nitrogen" again represents the sum of nitrate nitrogen and ammonia nitrogen.

For the categories "uptake by grain" and "returned to the soil as stover," the calculations were based on the work of Aldrich, *et al*,[12] using the 1975 WMS corn yield of 6,860 metric tons. A summary of Aldrich findings for N, P and K is presented in Table 67.

Table 67. ALDRICH DATA FOR CONCENTRATIONS OF NITROGEN, PHOSPHORUS, AND POTASSIUM IN CORN AND STOVER

Nutrient	In corn, kg/ha/kg yield	In stover, kg/ha/kg yield
Nitrogen	0.016	0.012
Phosphorus	0.003	0.002
Potassium	0.004	0.014

Discussion of Table 67 –

It should be understood that with a land treatment irrigation system of the dimensions of WMS some compromises with absolute accuracy must be allowed in attempts to account for all materials in and all materials out. In the case of BOD_5, the relationship is perhaps simplest: essentially what was applied to the field, minus small amounts (or none) out through the drainage pipes equals the amount "functionally" or "apparently" removed by the field. However, in the cases of nitrogen, phosphorus and potassium, consideration must be given to the amounts taken up by grain and returned to the soil in the stover. Even with these factors, the amounts of nutrients that are not accounted for are small.

The percentages of kilograms "apparently" removed by land treatment of nitrogen, phosphorus, potassium and chloride from Table 66 are 73.0, 99.0, 66.4 and 61.6 percent, respectively. These percentages reflect neither the amounts assimilated by the corn grain nor the amounts returned to the field as stover; however, such amounts are significant in all cases except chloride, which is essentially unaffected by plant uptake. By subtracting the amounts of each nutrient assimilated by the grain from the total kilograms removed, and by subtracting the amounts returned to the soil, one obtains the number of kilograms of each nutrient unaccounted for, the column at the bottom of Table 66. The assignment of these quantities of nutrients – a shortfall or "negative" amount in the case of nitrogen and excesses for phosphorus and potassium – may be done only with speculation. Possibilities include:

(1) The nutrients were retained in the "normal" groundwater-soil matrix and may be detected the following year as they are discharged into the drainpipes as a result of the spring thaw.

(2) Slight errors due to estimation of flows and/or other estimations, i.e., evapotranspiration rates.

For example, it was expected that some nutrients, particularly phosphorus, were retained within the soil profile. Such increases were found in soil analyses during the agricultural productivity studies. And, in the case of nitrogen, Aldrich estimates that of the 9,935 kg of nitrogen required per kilogram of corn yield, 0.028 kg are accounted for by the grain and stover. If the balance were retained by the root system, an additional 48 metric tons of nitrogen would be assigned to the plant-soil complex. One implication of this supposition would be that more nitrogen was used by the crop than was applied. This, too, would not be unreasonable, for soil analyses showed over time a decrease in nitrogen in the top 30 cm of soil.

During 1975 there was applied 100 metric tons of nitrogen as supplemental fertilizer during a period of maximum crop uptake. With the vast majority of that tonnage "committed" to the plant-soil complex, it was not believed likely that much of that supplemental (fertilizer) nitrogen was lost in discharge. The nitrogen which was "lost" from the system was probably leached out during periods of lowest plant activity. Some leaching is unavoidable at such times regardless of the cropping system.

Overall parameter removals for 1975, based on influent loading in Table 53 and the total amount lost through land treatment in Table 66, plus those losses from the interception ditches in Table 68, were as follows:

BOD	97.9%
Nitrogen	63.5%
Phosphorus	99.2%
Potassium	66.2%

The Lagoon Interception Ditches

Some volumes of lagoon wastewater are intercepted by ditches surrounding the lagoons, and such water may occasionally be pumped directly into the receiving Mosquito and Big Black Creeks. For the purposes of materials balance as a result of land treatment, the amounts of nutrients in this water are superfluous, for they are, in a manner of speaking, shunted through the system. All of the same chemical parameters are measured in the interception ditch water, and these data are presented in Table 68. They are the results of computations based on concentration data in Table 53 and flow volumes in Table 31.

Table 68. CALCULATED AMOUNTS OF MATERIALS DISCHARGED TO MOSQUITO CREEK AND BIG BLACK CREEK FROM THE LAGOON INTERCEPTION DITCHES, 1975, kg

Out through lagoon interception ditches to –	BOD	SS	N	P	K
Mosquito Creek via Ensley pump station	8.34x10^4	8.21x10^4	2.70x10^4	1.47x10^2	2.62x10^4
Big Black Creek via Sullivan	2.36x10^4	6.49x10^4	9.47x10^3	9.84x10^1	1.75x10^4
Total	1.07x10^5	1.57x10^5	3.65x10^4	2.45x10^2	4.37x10^4

The relationship between the impoundment lagoons and the interception ditches is worthy of further study. Continued regular monitoring of chemical parameters – especially phosphate – in the ditches should shed light on the relative effectiveness of the aquifer in removing wastewater nutrients and perhaps forecast the time at which the aquifer will reach nutrient saturation. Also, the continued monitoring of the discharge volumes from the interception ditches may reveal the rate at which the lagoon floors are sealing.

It is instructive to note that the mass of soil involved in this removal of phosphorus is in length about 150 to 180m in the direction of flow and is about 18m on the average in vertical thickness. Very little if any of the water movement is through the dikes themselves. The water moving through this aquifer is largely anaerobic, and the ability of the soil with its iron and aluminum to remove the phosphorus under these conditions is the most interesting aspect of the study which could be made. Furthermore, the removal is probably now about the same as that which takes place in the irrigation site itself, inasmuch as the phosphorus content of the water in the interception ditch is about the same as that in the drainage ditches which receive the flow from the plastic perforated drain pipes. The measured amount of P in the water in the drain pipe is very much lower than it is in the open ditch, the gain being contributed by the P which comes from the atmosphere and from the various life forms which get into the ditch. Similarly, it is likely that the P content of the water percolating through the saturated soils of the aquifer carrying the lagoon seepage water would be a great deal less than that of the water in the interception ditch.

SECTION 10

AGRICULTURAL PRODUCTIVITY STUDIES

OVERVIEW

Impressed on WMS farming operations was a set of priorities which relegates the profitability of crops to a position secondary to a new goal. That goal was to discover that group of plants which in interaction with local soils most effectively renovates Muskegon wastewater. Naturally, it was hoped that the crops would have market value, and the monies from crop sales would be recycled to contribute to the overall cost-effectiveness of wastewater treatment. But in setting high agricultural productivity as one of the goals of the WMS, it was with the understanding that farming operations were to achieve maximum recycling of wastewater nutrients while assenting to the harvest-market process to ameliorate costs.

These studies were begun in 1972 and have continued to the present. The early work focused upon evaluation of the performances of various crops under different environmental conditions and the collection of extensive baseline data; for instance, soil sampling begun in 1972 (and continued to the present) before and after cropping, and experimental crops grown both as dry-land and irrigated operations. Many of these early findings on the import of wastewater use on soil dynamics and plant physiology significantly affected decisions in management in subsequent years.

Corn emerged as the most likely crop target in 1972. The following years involved various corn trials, including evaluation of corn under varying nitrogen loads, and also shifts of research interest toward nutrient movement in soil, a subject pursued in 1975. In that same year, studies were done with application of nitrogen, sludge and lime to corn crops.

All of these subjects are discussed in detail in following sections, more or less chronologically, beginning with the 1972 corn variety tests and the 1973 corn trials, followed by the 1974 corn-wastewater irrigation studies and greenhouse lysimeter studies, and finally the 1975 research on nitrogen mobility and sludge application. The last section is a review of the soil testing program from 1972 through 1975.

1972 CORN VARIETY TEST PLOTS

The objective of this study was the selection of those corn hybrids best adapted to growth under the special soil-water conditions at WMS; among the criteria being evaluated were grain quality, moisture content of grain, and grain yield.

For each test plot it was assumed that field conditions – such as the distribution of wastewater, rate of fertilizer application, the measures for weed control, seed planting rate – were identical.

The accuracy of regulation of these factors was dependent upon various mechanical or hydraulic devices, the delivery of which was assumed to be constant.

Materials and Methods

An unirrigated four hectare area south of the east lagoon was selected for the trial. In order to minimize bias toward any particular seed or variety, plots for planting were selected on a random basis. The selection of the corn seed was based upon: the availability at the time, the judgment and experience of the farm manager, and Bulletin 431 of the Michigan Corn Production Extension series by E. Rossman, B. Darling and K. Dysinger, Michigan State University, East Lansing, Michigan, 1972. All test plots were planted May 30 through June 1, 1972. Corn maturities ranged from 82 to 109 days and included 43 varieties selected from nine companies. See Appendix F, Table 1 for specific variety-maturity data.

For each seed variety, two population densities were planted, each on a plot 0.02 ha in area and each with a row spacing of 97 cm. The higher population of 49,400 plants/ha was designated "A," and the lower, 38,500 plants/ha, was designated "B."

Herbicide application consisted of Lasso applied with Aatrex at rates of 3.5 liters/ha and 1.4 kg/ha, respectively.

Measurements –

Background soil samples were taken and analyzed for 11 parameters which are later discussed in detail. The recording of weather data included daily rainfall and temperature extremes, plus growing-degree days (GDD) for the season. Plant stand measurements were taken at emergence, mid-season and harvest. And at harvest, total grain yield and grain moisture content were measured and calculated for each plot.

Results

Weather –

The growing-degree days (GDD) for the season totalled 2,004, which is considered inadequate for good corn production. The daily weather data taken at the site appear in Appendix F. Table 2, and are inclusive for the period between May 31 and November 21, 1972. Between day of planting and the first killing frost in the fall, there were 130 days. A summary of the weather data is in Table 69.

Table 69. 1972 GROWING SEASON MONTHLY WEATHER STATISTICS

	Daily high			Daily low				
	Temp., °C			Temp., °C				
Month	Range	Avg.	SD	Range	Avg.	SD	Rainfall, cm	GDD
June	17→31	23	4	-1→16	10	4	10.4	395
July	16→31	25	4	7→24	15	4	8.30	561
August	17→31	25	4	3→19	13	4	18.7	546
September	12→29	22	3	0→17	10	5	8.20	364
October	3→23	13	5	- 9→15	2	6	9.40	114
November	2→15	7	4	- 6→10	2	4	2.40	9

Background Soil Samples –

The results of analyses on soil samples taken prior to the beginning of the agricultural productivity studies are in Table 70.

Table 70. 1972 CORN VARIETY PLOT SOIL DATA

Parameter	Average values
pH	4.5
Buffer pH	6.5
Percent organic matter	1.5
Nitrate nitrogen	5.6 kg/ha
Available phosphate	224 kg/ha
Exchangeable potassium	56 kg/ha
Exchangeable calcium	5,604 kg/ha
Exchangeable magnesium	448 kg/ha
Exchangeable manganese	9.0 kg/ha
Available zinc	0.7 kg/ha
Available sulfate	12.3 kg/ha

Plant stands –

Because of dry weather and rough field conditions at the time for planting, plant populations were less than predicted. The population data in Table 71 are a summary; specific information appears in Appendix F, Table 3.

Table 71. 1972 CORN POPULATION STATISTICS, PLANTS/ha

	Range	Average	SD
Emergence			
Plot A	28,700-54,800	38,300	5,500
Plot B	25,900-51,900	33,800	5,600
Mid-season			
Plot A	30,400-41,700	37,800	4,600
Plot B	21,200-45,200	33,100	4,100
Harvest			
Plot A	27,700-41,700	34,100	3,400
Plot B	24,900-40,500	30,600	5,300

Harvest –

A summary of the data for grain moisture content and grain yield for the two population plots is in Table 72 below. Specific data are in Appendix F, Table 4.

Table 72. 1972 HARVEST STATISTICS

Plots	Grain yield, metric tons/ha			Percent moisture content		
	Range	Avg	SD	Range	Avg	SD
A	2.96-4.80	3.86	0.46	28.0-40 +	34.8	3.9
B	2.89-5.20	3.86	0.51	26.0-40 +	34.3	4.0

Statistical Comparisons and Correlations –

Five correlation coefficients were calculated for each of the "A" and "B" populations and are presented in Table 73.

Table 73. "r" VALUES FOR 1972 CORN VARIETY PLOT COMPARISONS

Comparisons	"A" r value	"B" r value
Yield - population	0.27	-0.28
Yield - maturity	-0.11	-0.37
Yield - moisture content	-0.40	-0.55
Moisture content - population	-0.32	0.05
Moisture content - maturity	0.43	0.68

Hypothesis Test of Equal Means –

A "t" test was calculated for three different hypotheses. The results are listed in Table 74. and are compared to the 95 percent t value.

Table 74. "t" VALUES FOR 1972 CORN VARIETY PLOT HYPOTHESES

Hypothesis	Degrees of freedom	t calculated	t at 95 percent confidence level
A yield = B yield	40	-0.32	1.68
A population = B population	40	3.99	1.68
A moisture content = B moisture content	40	1.31	1.68

Analysis of Variance–

An "F" value of 3.97 was calculated testing the hypothesis of equal means between the corn varieties. The 95 percent "F" value was 1.69.

Conclusions

Little linear correlation was found between grain yield and plant population in either of the A or B corn trials. In the case of the later maturing varieties, the B populations showed a slight tendency toward less yield. With the higher population A plots, there was a suggestion of a tendency toward lower grain moisture content, and, in general, lower moisture content seemed to run parallel with higher yields. Also, moisture content had positive correlation with maturity in both population densities. At 95 percent confidence, there were no differences in yield and moisture content between A and B, although the A plots turned out to be significantly higher in plant population.

Based upon these initial hybrid performances, selection of the corn varieties for 1973 were made and included the following highest-yield corns:

Funks 5150, 4252
Pioneer 3956A
Teweles TXT 53, TXT 61 A
Trojan TXS94, TX100, TXS102

The selection trials for hybrids were conducted prior to the application of wastewater for a test period of one year only and under those prevailing weather conditions. However, the hybrids selected were representative varieties and were adaptable to the Muskegon soils and climate at the time of the tests.

Recommendations

It was recommended that a continued program of testing should be done each year to evaluate hybrid adaptability to the special conditions at a wastewater-renovation farm.

Other Crops Planted in 1972

Alfalfa, turf grass and other grasses were seeded in circle 40, but lack of supplemental irrigation water caused total failure of the crops. Soybeans and popcorn were tried in test plots but, due to late planting and a short growing season, failed to mature. In the border areas around the project, sweet corn and some vegetables grew well. It was recommended that all of the above crops be studied under fresh water irrigation and further research be done to determine the feasibility of and yield expectations from such crops.

1973 CORN TRIALS

The objectives this year were essentially the same as in 1972: evaluate corn varieties under current field conditions, which included evaluation of crop productivity as affected by the farming practices of the previous year. Again, the emphasis was on hybrid selection.

Except for size of plot, all field conditions within the three test areas were assumed to be identical. The known variable between the three fields was that each had during the previous year been subjected to a different cropping program.

Materials and Methods

As is illustrated in Figure 76 below, the west side of circle 40 was divided into three fields, designated A, B, and C, which were subdivided into 49 test plots. Field A, consisting of plots 1 through 21, had during the previous year a crop of uncut sorghum-sudangrass which was plowed back into the soil. Field B, made up of plots 22 through 29, had the previous year contained a crop of wheat which had been plowed down. And field C, plots 30 through 49, had contained corn which, after harvest of the grain, had been plowed under.

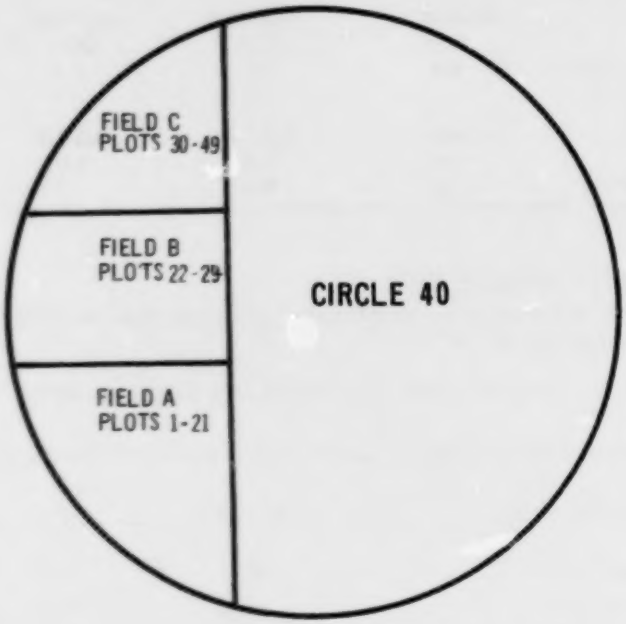

Figure 76. Corn trial plot organization, 1973

Corn varieties with maturation times ranging from 93 to 108 days were planted between May 29 and May 31, 1973. A comprehensive listing of the varieties and maturation times appears in Appendix F, Table 5. All plots were fertilized with wastewater containing enough nutrients to produce under ideal conditions at least six metric tons of grain per hectare.

Results

Summarized data for plant population, grain yield and grain moisture content are in Table 75 below. For the specific data, refer to Appendix F, Table 6.

Table 75. 1973 CORN TRIAL STATISTICS

Parameter	Plots 1-21	Plots 22-29	Plots 30-49	Total
Population, plants/ha				
Range	42,000-66,700	55,100-63,500	53,600-66,700	42,000-66,700
Average	57,600	59,000	60,600	59,000
Standard deviation	4,900	2,500	3,400	4,200
Percent moisture content				
Range	20.6-38.0	19.8-24.0	17.5-29.0	17.5-38.0
Average	25.0	21.5	20.4	22.6
Standard deviation	4.3	1.8	2.4	3.9
Yield, metric tons/ha				
Range	6.3-8.4	5.8-7.5	4.5-7.2	4.5-8.4
Average	7.3	6.8	5.6	6.5
Standard deviation	0.6	0.6	0.7	1.0

Statistical Comparisons and Correlations –

The same five pairs of data were compared in the 1973 study as in the 1972 variety trials. The "r" values are summarized in Table 76.

Table 76. CORRELATION COEFFICIENTS FOR 1973 CORN TRIALS

Comparisons	Total r value	Field A	Field B	Field C
Yield - population	-0.23	0.23	0.51	-0.29
Yield - maturity	0.67	-0.02	0.31	0.15
Yield - moisture content	0.45	-0.23	0.68	0.49
Moisture content - population	-0.47	-0.45	0.42	-0.24
Moisture content - maturity	0.71	0.67	0.64	0.40

Hypothesis Test of Equal Means –

Again, the "t" test was used, and the data are summarized in Table 77. including calculated and 95 percent values.

Table 77. "t" STATISTICS FOR 1973 CORN TRIALS

Hypothesis	Degrees of freedom	t calculated	t at 95 percent confidence level
A yield = B yield	27	1.90	1.70
B yield = C yield	26	4.06	1.70
A yield = C yield	39	8.13	1.68
A moisture content = B moisture content	27	2.18	1.70
B moisture content = C moisture content	26	1.16	1.70
A moisture content = C moisture content	39	4.14	1.68
A population = B population	27	-1.04	1.70
B population = C population	26	-0.88	1.70
A population = C population	39	-2.32	1.68

Conclusions

The positive linear correlation between yield and population in field A to some extent suggests a trend toward larger yield with higher population. The overall yield-maturity relationship was biased because of plantings having been done on plots of different cropping histories, but in spite of the fact that individual plots indicate no correlation, the macroscopic view suggests correlation. Field B showed some positive linear correlation between grain yield and moisture content, which suggests that in going for higher yields, a higher moisture content in the grain must be tolerated. There is a hint of a trend in the relationship between declining moisture content with increasing population, with relatively negative r values for this comparison. It is likely that a large population of corn, in using water from the soil at a higher rate, would dry down faster than a less dense population. As in the 1972 study, the best correlation is the positive relationship between moisture content and grain maturity. It is established that longer maturing varieties take longer to dry down.

The "t" values in Table 77 show a significant difference between all fields, ranking them A, B, and C in decreasing yields. The sorghum-sudangrass plowdown produced the best yields, followed by the wheat stubble and corn stalks. It would appear, in this case, that the more organic material returned to the soil, the greater the yield the following year. Because of the maturity bias, the moisture content of field A was significantly higher than either of the other two plots. A significantly higher population was seen in field C over field A and was the only measurable difference between fields.

Recommendations

As in 1972, the results of these plantings affected crop management for 1974, with the best of the hybrids comprising the major part of the 1974 planted acreage. It was recommended that future corn trials be planted on a larger scale – perhaps half or entire fields – in order to achieve better crop representation. Since 1973 was such a poor year for crop growth and because field conditions were so poor, a continuing program to choose hybrids that would do well under the gradually improved field conditions should be followed.

1974 CORN EVALUATION TEST PLOTS WITH WASTEWATER AND FERTILIZER

The objectives of this study were to find the optimum rates of wastewater application and to test those rates with and without supplemental potassium fertilizer. Throughout these tests, as previously, it was assumed that the hydraulic and mechanical devices delivering water, fertilizer and herbicide were doing so equally. The soil in the test area was presumed to be uniformly of the same type.

Materials and Methods

Test plots measuring 7.6 by 39.6 meters were laid out in circle 55, an area of sandy Rubicon soil. See illustration in Figure 77. The concentric circles diagrammatically show the wheel tracks of the corresponding towers on the irrigation rig. Thus individual segments of the spray bars could be manipulated to provide the three application rates of 2.5, 6.4, and 8.9 cm/week of effluent, being irrigated 2, 5 and 7 days per week, respectively.

Corn was planted and "treated" by three different rates of effluent application, both with and without supplemental potassium fertilizer. No fertilizer was added to subplots 1 and 3. Prior to planting, 168 kg/ha of potassium fertilizer was applied to subplots 2 and 4. All plots were planted May 21, 1974, with Funks 4343 corn, and the weekly irrigation rates were maintained from June 5 to October 5, 1974. In mid-June herbicides were applied equally to all plots: Aatrex and crop oil went on at rates of 2.2 kg/ha and 9.4 l/ha, respectively.

At harvest the corn from each plot was measured for moisture content, grain yield, stalk height and ear height.

Results

A summary of the data appears in Table 78.

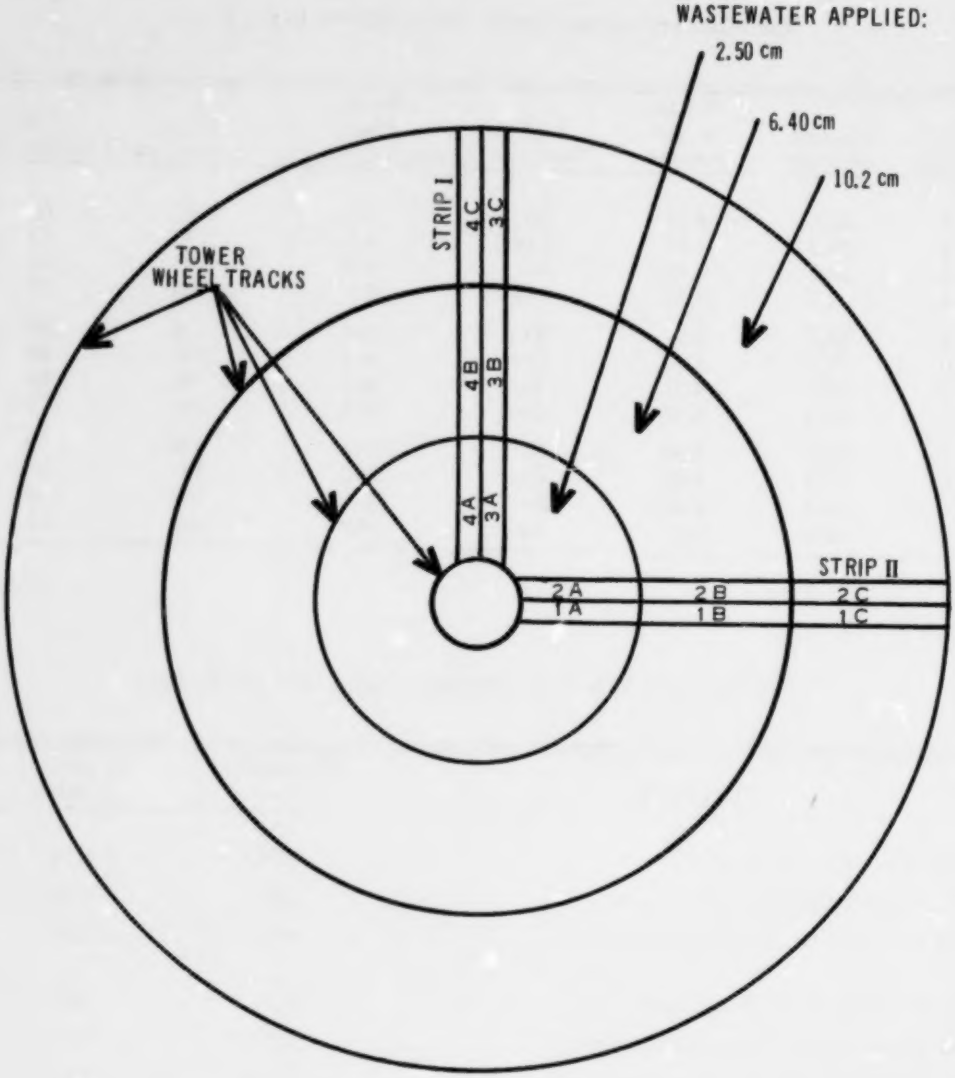

Figure 77. Corn evaluation test areas
Subplots 1 & 3 without fertilizer
Subplots 2 & 4 with fertilizer

Table 78. 1974 CORN CROP EVALUATION PLOT DATA

Plot Number	Percent moisture	Yield, metric tons/ha	K_2O fertilizer	Weekly effluent application, cm	Stalk height, cm	Ear height, cm
1 A	27.3	4.65	No	2.5	203	66
2 A	29.2	2.95	Yes	2.5	203	69
3 A	26.9	4.65	No	2.5	203	64
4 A	23.7	2.57	Yes	2.5	203	74
1 B	30.4	3.96	No	6.4	244	86
2 B	31.0	4.65	Yes	6.4	244	89
3 B	25.8	4.21	No	6.4	244	86
4 B	24.4	6.47	Yes	6.4	236	76
1 C	32.5	3.96	No	10.2	244	89
2 C	27.3	4.81	Yes	10.2	239	84
3 C	26.7	6.59	No	10.2	264	124
4 C	26.0	6.61	Yes	10.2	248	91

Table 79. ANALYSIS OF VARIANCE FOR CROP TEST, 1974

Hypothesis	Calculated F value	95 percent F value
Yield in A, B, C the same	2.24	4.26
Yield in all fertilized plots the same	4.66	9.55
Yield in all unfertilized plots the same	0.58	9.55
Stalk height in A, B, C the same	51.74	4.26
Stalk height in fertilized plots the same	33.73	9.55
Stalk height in unfertilized plots the same	21.00	9.55
Ear height in A, B, C the same	6.57	4.26
Ear height in fertilized plots the same	3.50	9.55
Ear height in unfertilized plots the same	4.15	9.55
Moisture content in A, B, C the same	0.25	4.26

Statistical Comparisons –
The paired "t" test was used to compare 17 sets of data, and these results are tabulated in Table 80.

Analysis of Variance –
The "F" test was used to test hypothesis of equal means between more than two groups. The hypotheses and F values are listed in Table 79, on page 194.

Table 80. PAIRED "t" STATISTICS FOR 1974 CROP TEST

Hypothesis	Degrees of freedom	$t_{\text{calculated}}$	t at 95 percent confidence level
Strip I yield = strip II yield	5	2.07	2.02
Fertilized plot yield = unfertilized plot yield	5	0	2.02
Fertilized stalk height = unfertilized stalk height	5	1.07	2.02
Fertilized ear height = unfertilized ear height	5	0.83	2.02
A yield = B yield	3	1.05	2.35
B yield = C yield	3	1.14	2.35
A yield = C yield	3	1.81	2.35
Strip I moisture content = strip II moisture content	5	3.85	2.02
Moisture content fertilized = moisture content unfertilized	5	1.27	2.02
A stalk height = B stalk height	3	15.0	2.35
B stalk height = C stalk height	3	1.2	2.35
A stalk height = C stalk height	3	8.16	2.35
A ear height = B ear height	3	3.52	2.35
B ear height = C ear height	3	1.34	2.35
A ear height = C ear height	3	2.73	2.35
Strip I stalk height = strip II stalk height	5	1.87	2.02
Strip I ear height = strip II ear height	5	0.89	2.02

Conclusions

Significant differences were found between three parameters in this experiment. The test strip containing replicate plots 3 and 4 showed a grain yield which was significantly greater than in the strip containing replicate plots 1 and 2. Similarly, the moisture content of the grain from 3 and 4 was significantly less than that from 1 and 2. Those plots designated as "C" contained corn with stalk and ear height significantly higher than those from "A" and "B." No other factors tested were different at the 95 percent confidence level.

From Table 78 it is evident that the highest yields were in those fields receiving the most irrigation, but the correlation does not hold up statistically. Whereas this piece of work does indicate that heavy irrigation is not harmful to corn grown in this soil type, it also indicates that supplemental potassium fertilizer is not terribly helpful. Indeed, at the lowest application rate, potassium fertilizer was detrimental to crop yield, a phenomenon which may occur because, as a salt, potassium can interfere with germination if water is not sufficiently abundant to disperse it.

It was recommended that in the future more replicates be included in the experimental design to increase the probability of statistical validity.

GROWTH BOX LYSIMETER STUDY, 1974

The objective of this experiment was to miniaturize a segment of the irrigated site farmland in a controlled environment in order to study the rates of nutrient uptake of corn and alfalfa from wastewater under varying hydraulic and nutrient loadings and to simultaneously monitor nutrient leaching under these conditions.

It was assumed that soil, water and nutrients were identical. Rate of seed planting was constant. The light distribution over the boxes was assumed to be the same, and the temperature inside the greenhouse was controlled.

Materials and Methods

Because it is the most common soil type at WMS, Roscommon sand was selected for this study. In preparation for soil excavation, the site was closely mowed and then raked to remove grass and debris before repeated discings. As the soil from the three soil layers was removed, it was segregated into three piles. The topsoil, or horizon A, extended to a depth of 15 cm. The upper C horizon extended from a depth of 15 cm to 79 cm, and the lower C horizon from 79 cm to 114 cm, the limit of excavation.

Plywood cubes, 1.2 m on a side, were constructed and lined with polyethylene sheeting. In the corner of the bottom of each cube, an 8 cm diameter hole was cut to accommodate a plastic funnel which was sealed with wax and was capped with a perforated plastic disc; through this drainage hole leachate was collected for analysis.

The contents of the boxes were as follows: on the bottom to a depth of a few centimeters, washed pea gravel was layered with a sheet of filtering fabric (similar to that used in drain tiles); next the soils were layered carefully in the same sequence as they were excavated.

A horizon	15 cm
C upper	64 cm
C lower	35 cm

Between each layering, the soil was leveled and raked to break up the surface. A total of 38 boxes were so constructed and then arranged in a greenhouse in such a manner that each tilted slightly toward the funnel-corner.

Figure 78 is a sketch of a lysimeter box.

Experimental Design

In order to establish the treatment regimes to be used for the lysimeter boxes, it was first determined what the "reasonable" yield goals should be for corn and for alfalfa. Goals of 5.0 to 6.3 metric tons/ha for corn and 6.7 to 9.0 metric tons/ha for alfalfa were decided upon.

Average analyses of treated lagoon effluent were made and extrapolated to determine the total effluent nutrient loading per year under each of two irrigation regimens, 6.4 and 10.2 cm/wk, for a total of 30 weeks per year. These data in combination with data from soil analyses provided a complete nutrient profile which, when compared to the calculated requirements of nitrogen, phosphorus and potassium, gave clear indication as to whether supplemental fertilizer would be necessary to achieve the anticipated crop yields. See Appendix F, Table 7.

For reasonable yields of corn and alfalfa, the following nutrient needs were calculated:

		kg/ha
Corn	Nitrogen	174
	Phosphorus	123
	Potassium	239
Alfalfa	Nitrogen	28
	Phosphorus	95
	Potassium	239

The treatment program was divided into six different nutrient loadings, each in triplicate for two different crops, thereby using 36 lysimeters. Before beginning the experiment, a randomized block design was drawn up to determine allocation of treatments to the various boxes. The six treatments were:

A - 6.4 cm of effluent plus rainfall per week

B - 10.4 cm of effluent plus rainfall per week

C - 6.4 cm of effluent plus rainfall with supplemental fertilizer

D - 10.2 cm of effluent plus rainfall with supplemental fertilizer

E - 6.4 cm of effluent plus rainfall per week with limed soil (Lime applied at 7 metric tons/ha)

F - Irrigation 2.5 cm analyzed well water per week with complete fertilizer

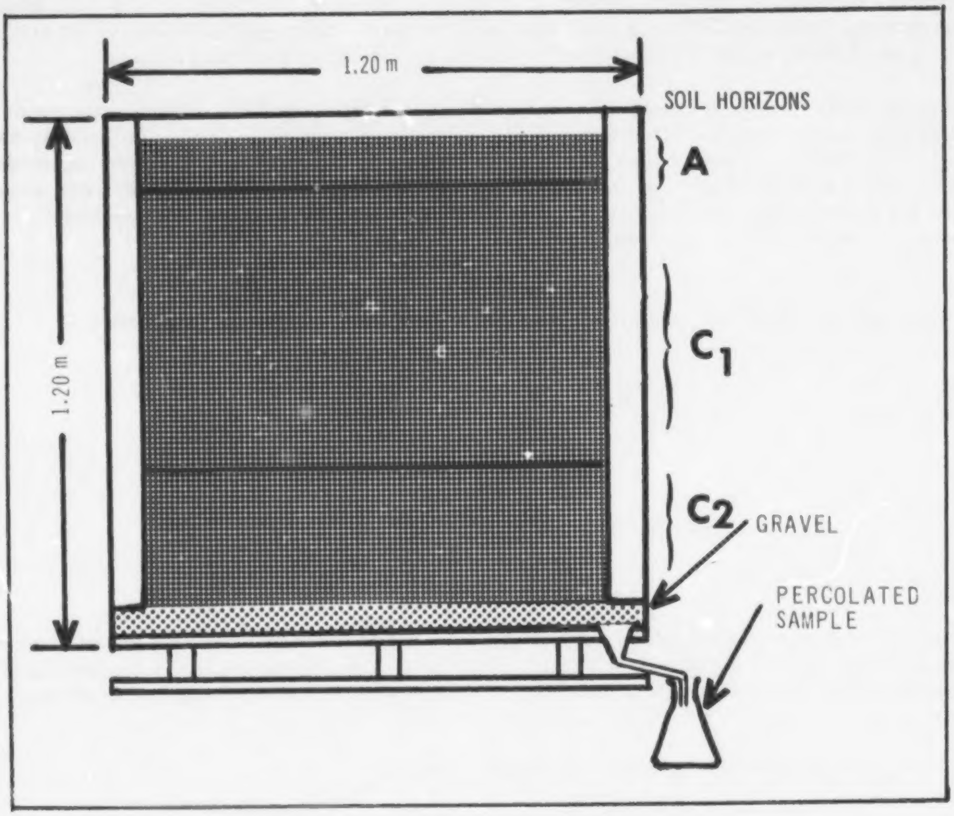

Figure 78. Growth box lysimeter

Rainfall was simulated by the application of fresh water at the rate of 1.3 cm/wk. Treatments A through E tested the effects of two application rates of effluent with each of three soil variations; these variations consisted of no-fertilizer-no-lime, plus lime only, and plus fertilizer only. Treatment F was designed as a control to simulate conventional agriculture by the use of irrigation and complete fertilizer. It should be noted that in the case of alfalfa with an application rate of 10.2 cm effluent, no supplemental fertilizer would be required to meet yield goals.[13] So three boxes were dropped from the total, leaving 33.

Soon after the applications of lime and fertilizer, the corn boxes were seeded by placement of three kernels in each of eight positions, as is illustrated in Figure 79. After emergence of the seedling and some growth, all corn plants but the healthiest were removed from each planting site, leaving a plant-per-box population equivalent of 53,800 plants/ha.

In the case of alfalfa, the boxes were seeded by hand in hopes of achieving a more even stand. The seeds were lightly raked into the soil at a depth of 0.6 cm and at a population equivalent of 16.8 kg/ha.

The effluent for irrigation of the lysimeters was aerated wastewater which was chlorinated and stored for two days to allow settling of solids before use. Irrigation continued between December 11, 1973, and March 11, 1974. Weekly samples of the irrigation water and of the leachate were analyzed for nutrients. Appendix F, Table 8, contains the data from the effluent analyses (14 parameters); Appendix F, Table 9, shows the amounts of nutrients weekly and for the total period of the experiment; Appendix F, Table 10 contains those data for the control lysimeters, showing amounts applied in fresh water only.

Results

The greenhouse did not provide good growing conditions. Because it was winter and light was inadequate, the corn crop failed to grow above 10 to 15 cm high. This alone introduced a devastating bias into the experiment, which was further complicated by the fact that the alfalfa experienced normal growth. Comparison of the two crops was therefore impossible.

However, comparisons were made of the loadings and leachings of each lysimeter. Leachate nutrients were measured and expressed as concentrations based upon the assumption that as much water drained from the system as was applied. The results extrapolated to kg/ha are in Appendix F, Table 11. The absence of chromium and lead data in the leachate results is because their levels were below the detection limits of the instrumentation.

Statistical Comparisons –

Although statistical comparisons were made between all parameters, the conclusions that might be drawn from them are hazardous because of the extraordinary bias. However, those significant differences found to be at the 95 percent confidence level are listed in Tables 81 and 82.

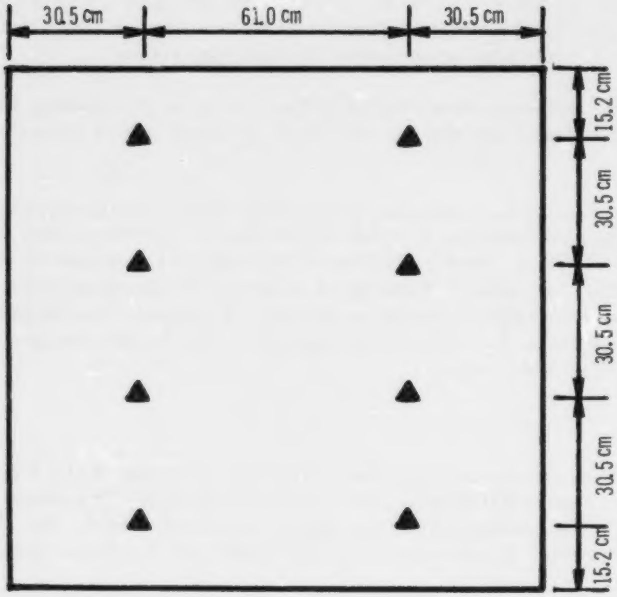

Figure 79. Corn plant arrangement within the growth box

Table 81. SIGNIFICANT TREATMENT COMPARISONS FOR 1974 GROWTH BOX STUDIES

Treatment	leached significantly more (parameter)	than treatment	under crop
B	Ca, Mg, Na, SO_4, Cl	A	corn, alfalfa
B	K, Zn	A	corn
D	Na, SO_4, Cl	C	corn, alfalfa
D	K, Zn	C	corn
C	NO_3	D	corn
D	Ca, Mg	C	alfalfa
E	NH_3, Mg, SO_4	A	alfalfa
C	NO_3, Ca	A	corn
C	Cl	A	alfalfa
D	PO_4, K, Ca, Mg, Na, Zn, SO_4, Cl	F	corn, alfalfa
D	NH_3	F	alfalfa
F	NO_3	D	corn

Table 82. SIGNIFICANT CROP COMPARISONS FOR 1974 GROWTH BOX STUDIES

Crop	leached significantly more (parameter)	than crop	under treatment
Alfalfa	K, NH_4, PO_4, Na, Cl	corn	A
Corn	NO_3, Ca, Mg	alfalfa	A
Corn	NO_3	alfalfa	B
Alfalfa	Na	corn	B
Corn	NO_3, Ca, Mg	alfalfa	C
Alfalfa	Na, Cl	corn	C
Alfalfa	PO_4, Na	corn	D
Corn	NO_3	alfalfa	D
Alfalfa	K, NH_4, PO_4, Na, Cl	corn	E
Corn	NO_3	alfalfa	E
Corn	NO_3, Mg	alfalfa	F
Alfalfa	SO_4	corn	F

Conclusions

It should be recalled that the validity of the above comparisons extends only through the first 10 to 15 cm of corn growth.

Nitrate ion does seem to leach more readily under corn than under alfalfa under all treatment conditions.

The research data suggest many interesting tendencies which could be elaborated upon in an expanded experimental model which would be similarly monitored and would be undertaken with the benefit of a full growing season.

1975 PRELIMINARY NITROGEN STUDY

Objectives and Assumptions

It has long been assumed that nitrates applied in solution pass readily through sandy soils and that nitrates produced by micro-organism activity in sandy soils are readily leached by heavy rain and/or irrigation. The extent to which such movement occurs is of critical importance to management of wastewater irrigation and nitrogen application. During 1974, the entire WMS corn crop showed extensive injury from nitrogen starvation. Because the "living filter" concept depends upon good crop production, it was decided that nitrogen would be applied in 1975.

Accordingly, arrangements were made to introduce 28 percent liquid nitrogen into the irrigation lines at the pivots. To avoid leaching of nitrates from the profile, the nutrient was applied in small amounts (11.2 kg/ha per application) and did not start until tissue tests indicated nitrogen deficiency. In an effort to discover how fast and how deep nitrogen moves into the soil when applied through the irrigation rigs, samples of the two soil layers were taken several times during the season. This study was also to serve as a pilot program to determine the direction of further research.

It was assumed that the fields in this study were equal with respect to soil, water and nutrient factors.

Materials and Methods

Sandy soil of the Roscommon and Rubicon types were selected for this study because of their high permeability and local abundance. Representative plots were chosen in four circles: two in circle 16 and one each in circles 20, 21, and 54.

In each plot, stakes were driven into the soil 30 m apart. Sets of soil core samples going down to 20 cm were taken between each pair of stakes. Each set of samples numbered 20, and those samples taken at depths from 0 to 10 cm were compared to those at depths of 10 to 20 cm. Background samples were taken before application of nitrogen. All sets were analyzed for nitrite and nitrate.

On each sampling date, between five and ten plant samples were also taken for semi-quantitative analysis of tissue nitrogen.

Results

Specific data pertaining to nitrogen application and soil test results for the four fields appear in Appendix F, Table 12. Representative data for plant tissue determination, fertigation schedule and soil nitrogen are in Figure 80. Approximations of nitrogen balance are in Table 83.

Table 83. NITROGEN BALANCE, kg/ha

Field	Wastewater applied N[a]	N fertilizer applied[b]	Total N applied[c]	N assimilated in plants[c]	N unaccounted for
16	55	100	155	159	- 4
20	65	73	138	179	-41
21	78	92	170	170	0
54	127	62	188	130	58

[a] N applied prior to and during crop growing season from Appendix F, Table 12

[b] From Appendix F, Table 13, as 28 percent liquid nitrogen

[c] From harvest data in Appendix G, Table 17, and assuming 1 kg N/28 kg of Number 2 corn

Statistical Comparisons –

Table 84 contains averages and standard deviations of the nitrogen levels in the soil samples. Table 85 shows "r" and "t" values calculated for comparisons between the two soil layers sampled.

Table 84. 1975 NITROGEN STUDY STATISTICS

	Soil nitrate levels in kg/ha			
	0-10 cm		10-20 cm	
Field	Average	SD	Average	SD
16 A	8.4	4.2	3.5	1.7
16 B	7.1	4.4	4.2	3.1
20	18.5	13.2	8.5	4.8
21	8.2	4.6	3.7	1.2
54	16.6	9.5	11.2	7.4

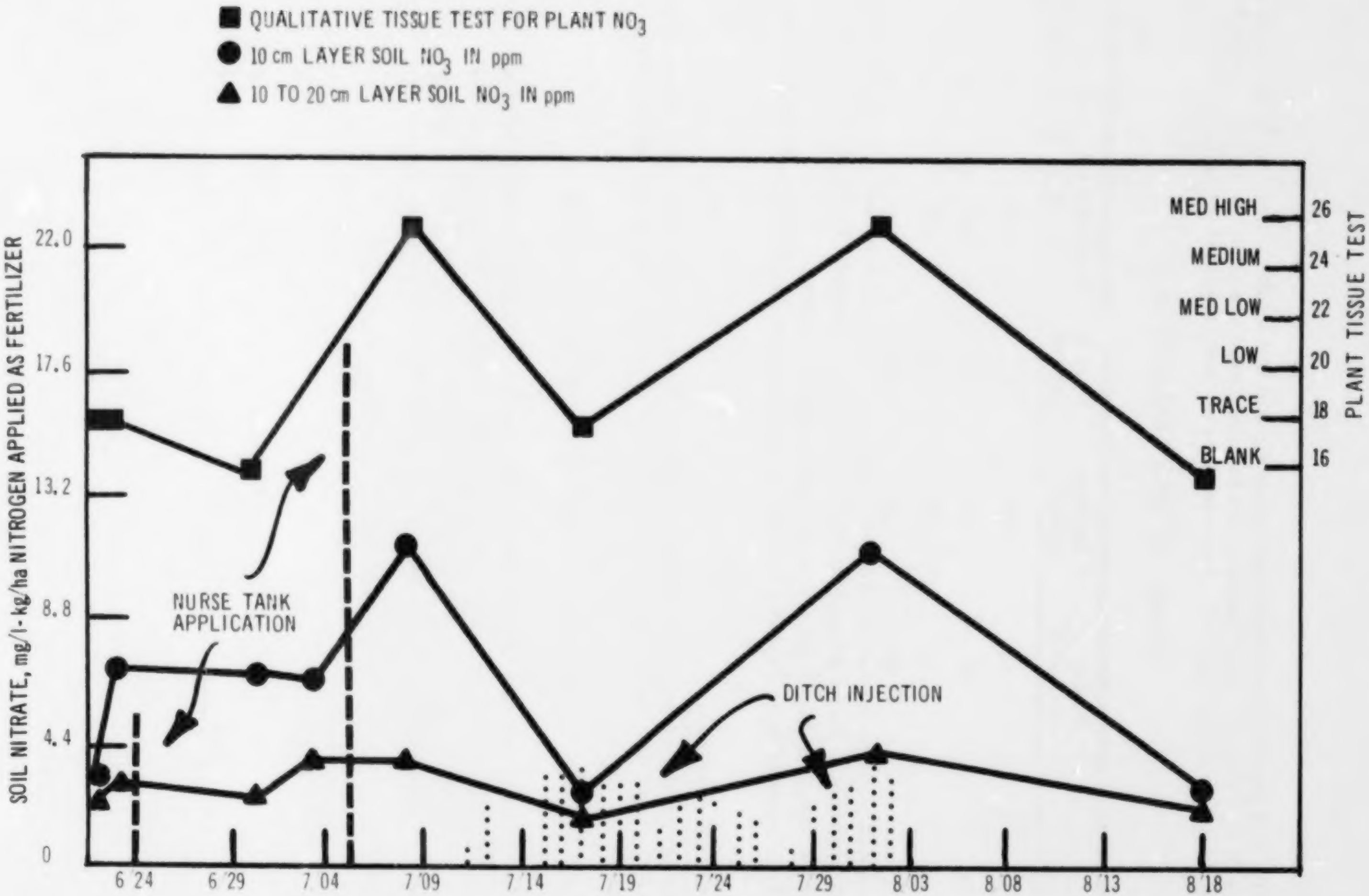

Figure 80. Nitrate nitrogen in two soil layers under nitrogen fertigation in field 21.

Table 85. 1975 NITROGEN STUDY "r" AND "t" VALUES FOR
0 to 10 cm vs 10 to 20 cm

Field	r value	Paired t test at 95 percent level		
		Critical t	Calculated t	Degrees of freedom
16 A	0.92	1.9	5.3	7
16 B	0.96	2.1	3.9	4
20	0.84	1.9	3.5	7
21	0.87	1.9	2.8	6
54	0.82	1.9	2.6	6

Conclusions

As is illustrated in Figure 80 and by the data in Appendix F, Table 14, an appreciable portion of the applied nitrogen was temporarily retained near the soil surface. In all comparisons, the top 10 cm of soil contained significantly more nitrate than did the second 10 cm. This retention was probably attributable to the amount of organic matter in the soil, however small. Although the results may not prove that nitrogen did not move out of the profile, they certainly suggest that much of the amount of applied nitrogen remained near the surface, where a majority of the root uptake occurs.

It is presumed in the concept of nitrogen balance that the amount of nitrogen in the soil at harvest is the same as the amount prior to irrigation. Credence is lent to this equation by the results of the analyses of the soil samples taken in spring and fall, for the corn seems to account for the majority of the nitrogen applied. Good linear correlation between the two horizons with respect to nitrate content would – if present – indicate a constancy of nitrogen movement through the soil profile. These research results were titillating, hinting at larger truths which, with larger-scale continued research, would be revealed with statistical dependability.

APPLICATION OF SLUDGE IN 1975

Objectives and Assumptions

The primary objective of this research was to observe the effects on crops of the application of domestic sludge on sandy soil under heavy irrigation. It was speculated that the organic matter in sludge would make such a contribution to the soil that nutrient-holding capacity would be enhanced, thereby making nutrients more available for crop assimilation. This aspect was evaluated.

It was assumed that the rates of water and fertilizer application were equal. Corn variety and planting rates were constant. Except for the sludge application on the experimental section, all field conditions were assumed to be equal.

Materials and Methods

Between March 25 and April 23, 1975, 10,000 cubic meters of domestic sludge (7% solids lime stabilized at pH 9-10) were applied to the northeast half of circle 34 at a rate of 4.6 metric tons of liquid per hectare. To this half and to the adjacent half circle as a control, Trojan TXS94 corn was planted at a rate of 52,000 plants per hectare. During the growing season the corn crop was irrigated with 124 cm of wastewater and recieved 48 cm of rainfall.

The analysis of the sludge appears below in Table 86. It is readily evident that the sludge was high in organics but low in plant nutrients. The nutrient contributions of the wastewater plus supplemental nitrogen are summarized in Table 87.

Table 86. SLUDGE CHARACTERISTICS AND APPLICATION RATE, 1975

Parameter	ppm single sample	kg/ha
NH_4-N	290	1.4
NO_2-N	0.1	0
NO_3-N	0.1	0
TKN	305	1.4
SO_4	ND	0
PO_4-P	14.8	0.1
TP	19.0	0.1
Cl	89.0	0.4

Table 87. NUTRIENT APPLICATION BY WASTEWATER IN SLUDGE STUDY, 1975

		kg/ha
Wastewater	N	79
	P	19
	K	114
Supplemental	N	27
Total	N	106

Results

The corn crop was harvested November 25, 1975, with careful separation between the sludge and no-sludge plants.

Treatment	Yield, metric tons/ha	Moisture content, percent water
Sludge	4.4	21.4
No sludge	3.0	20.5

Conclusions and Recommendations

Yield was dramatically increased by sludge application, and since the increase could not be attributed to the nutrients of sludge, it must have been that the increase was due to the environment created by the sludge, one of enhancement of nutrient assimilation. However, these data are only suggestive due to the fact that a replicate test was not performed. It was recommended that further work be done with varying amounts of sludge with parallel monitoring of multiple soil parameters.

NITROGEN FERTILITY RESEARCH 1975

Objectives and Assumptions

In that the 1974 season had shown nitrogen to be an important limiting factor in many of the fields, the purpose of this study was to quantify any increase in yield due to the addition of nitrogen. Other factors to be compared with controls were grain moisture content and general appearance.

It was assumed that the application of wastewater in all plots was even and that the application of supplemental nitrogen to the experimental crop was the only difference between fields.

Materials and Methods

Trojan TXS 95 corn was planted to the sandy Roscommon soil of circles 28 and 29 at a planting rate to give 52,200 plants/ha. Circle 28 was control, and circle 29 received seven doses of nitrogen (9 to 10 kg/ha) during periods of peak crop need, providing a total nitrogen supplement of 75 kg/ha. Periodic tissue analyses of the corn tissue provided a guide for applications. The nitrogen was injected into the irrigation rig at circle 29.

Results

In Table 88 below is a listing of the major nutrients applied to the control and experimental fields during the growing season.

Table 88. 1975 NITROGEN FERTILITY DATA

Nutrient		Applied to field 28, kg/ha	Applied to field 29, kg/ha
Wastewater	N	100	75
	P	22	18
	K	137	102
Supplemental	N	12	84
Total	N	112	159

The two circles were harvested between October 23 and 27, 1975.

The moisture content of the grain was essentially the same, 20.5 percent for the supplement, 22.1 percent for the control. But the yields differed significantly, with 3.9 metric tons/ha for the control and 4.7 for the supplement. The analyses of phosphorus and potassium in the soil samples and plant tissue samples indicated that they were not limiting factors in this experiment.

Conclusions and Recommendations

Supplemental nitrogen significantly increased corn yield in this experiment. It was recommended that these experiments be continued to discover the optimum rate of nitrogen application for maximum crop assimilation and minimum leaching.

INSECTICIDE LEVELS IN HARVESTED GRAIN

Samples of grain were sent to the Wisconsin Alumni Research Foundation, Madison, Wisconsin, for detection of insecticide residues in corn tissue, and the results indicated either insignificant traces or none at all. These data appear in Appendix F, Table 15.

SOILS TESTING PROGRAM, 1972 THROUGH 1975

Objectives and Assumptions

The main objective of these tests was to monitor the concentrations and movements of those chemicals regarded as important to crop growth, grain yield, grain quality and wastewater renovation.

It was assumed that all samples taken within each soil type were representative of that series.

The number of replications comprising each sample was believed to portray an unbiased composite of the particular field from which the sample was taken.

Materials and Methods

The methods used in soil testing at the WMS farm laboratory are summarized below.

Procedures from the Ohio State University Testing Laboratory

a. Soil pH - water extraction

b. Buffer pH - buffer addition

c. Organic matter - combustion at 500°C

Procedures from Monograph No. 9 of the American Society of Agronomy

a. Available phosphorus - Bray's test for monophosphate

b. Nitrate nitrogen - calcium sulfate extraction

c. Ammonium nitrogen - potassium chloride extraction

d. Potassium, sodium, calcium, magnesium - ammonium acetate extraction

e. Cation exchange capacity - sodium saturation

f. Zinc - diethylenetriaminepentaacetic acid extraction

The soil types at the WMS site were determined by field observation and by reference to previous work.[14] The actual points from which samples were taken depended upon both soil type and circle location, but all soil types were sampled for the baseline study in 1972-1973. At each sampling point, a pipe three meters long was driven one meter into the soil and painted so as to be outstanding even in mature corn.

Each of the predominant soil types was sampled at least ten times and each of the minor soil types at least three times. A bucket auger was used to drill to a 1.5 m depth, and sets of 20 core composites were obtained for each of six depths: 0 to 15 cm, 15 to 31 cm, 31 to 61 cm, 61 to 91 cm, 91 to 122 cm, and 122 to 152 cm. For each major soil type, six replicate fields were chosen as a good representation. The samples were air dried and run through an 18 mesh sieve to break up cemented clods of soil. Large undecomposed organic materials such as roots, grass and wood were removed and discarded, but all stones and fine gravel were returned to the soil sample and thoroughly mixed. The samples were then stored in one liter glass mason jars for subsequent analysis.

Sampling was done in the fall of 1972, 1973, 1974 and in the spring of 1975.

A generalized sketch of these major soil types appears in the section on Design Criteria.

Results

Detailed results from these determinations appear in Appendix F, Table 14.

The statistical comparisons listed below in Tables 89 and 90 represent composites of the six replicate fields in each soil series. For the ten parameters, the "t" values are in Table 89 and the "F" values for analysis of variance are in Table 84.

Table 89 indicates a significant difference between the four soil series for the different parameters. Additional statistical analysis should be done to show significantly low or high parameters with the soil types.

Table 89. SOIL PARAMETER COMPARISONS BETWEEN SEASONS BY HORIZON AND SOIL TYPE - PAIRED "t" TEST

	Fall 1972 Fall 1973	Fall 1973 Fall 1974[b]			Fall 1974 Spring 1975		
Parameter	0-31 cm[a]	0-31 cm	31-61 cm	61-91 cm	0-31 cm	31-61 cm	61-91 cm
pH	0	+RS	0	0	0	0	0
Percent OM	0	0	+R	+RA	0	0	0
Na	−R	+RSA	+RSA	+RSA	−RSA	0	−RA
NO_3	N	−A	0	0	0	0	0
NH_4	N	+R	−A	−A	0	+SA	+SA
K	0	+RS	−G	−G	+G	+G	0
Ca	0	+R	0	−G	0	+G	+G
Mg	−R	+R	−G	0	+A	+AG	0
P	0	0	0	0	0	0	−G
CEC	N	0	−G	−RS	0	+G	+G

+ = significant increase
− = significant decrease
R = Rubicon
S = Roscommon
A = Au Gres
G = Granby
0 = no significant changes in any soil type
N = not tested

[a] Rubicon compared only

[b] Irrigation began during the summer, 1974, as rigs became available

Table 90. ANALYSIS OF VARIANCE TEST FOR SIGNIFICANT DIFFERENCES BETWEEN SOIL SERIES

Parameter	0-31 cm	31-61 cm	61-91 cm
pH	73[a]	73,74	73,74,75
Percent OM	-	-	-
Na	-	-	-
NO_3	-	75	-
NH_4	-	75	74
K	73	-	73
Ca	75	75	-
Mg	73,74,75	-	73,74,75
P	73,74,75	73,74,75	73,74,75
CEC[b]	73	-	-

[a] 73 = Fall 1973; 74 = Fall 1974; 75 = Spring 1975

[b] Cation exchange capacity

Conclusions and Recommendations

From the fall of 1972 to the fall of 1973, little irrigation had been done, so it is not surprising to find few significant changes in soil parameters. As to the decrease in sodium and magnesium in the Rubicon series, it is probable that the heavy rains experienced immediately after clearing operations made a contribution to this leaching.

From the fall of 1973 to the fall of 1974, the majority of the irrigation rigs had become operative, resulting in dramatic changes in the soil profiles. Rubicon topsoil increased in pH, sodium, ammonium-nitrogen, potassium, calcium, and magnesium during this period. Similarly, Roscommon showed increases in pH, sodium, and potassium in the topsoil. Au Gres also increased in sodium in topsoil. These various increases may be attributed to wastewater irrigation, as the data indicates the soils most affected were those receiving the most irrigation. As to the decrease in nitrate-nitrogen in the upper meter of Au Gres, it is likely that the combination of heavy irrigation and poor corn growth may have resulted in the leaching of nitrates to a horizon deeper than one meter. Ammonium-nitrogen decreased in the lower two levels of the Au Gres from 1973 to 1974. While the Rubicon and Roscommon soils showed a loss of cation exchange capacity only in the lowest measured layer, the Granby series exhibited lower levels of potassium, calcium, magnesium, and cation exchange capacity in one or both of the lower levels. Many of these phenomena require further study to understand the complex behavior patterns of the soils under varying nutrient loadings.

From the fall of 1974 to the spring of 1975 there occurred changes in soil parameters within a given soil series which were opposite to the trends of the previous year. See Appendix F, Table 14. Sodium, ammonium-nitrogen, calcium, magnesium, and cation exchange capacity all showed reversals of the 1973/1974 trends. It was speculated that "wintering effect" played a role in these changes, but more data over a period of more years are needed before dependable patterns may be experienced. It was recommended that this program be ongoing and expanded in order that such findings may more directly influence farm management and, ultimately, wastewater renovation at WMS.

SECTION 11

MANAGEMENT OF FARMING OPERATIONS

HISTORY

Because the first major task of the first farm manager was the development of detailed plans for all agricultural activities, the following programs were prescribed:

1. The study of cover crops with respect to their nutrient needs, water requirements and adaptability to soil conditions at the time
2. The study of various crops for maximum utilization of effluent nutrients under heavy irrigation
3. In border areas outside the irrigated fields, the study of how test crops influence soil stability and overall land productivity
4. The delineation annually of a master farm plan which outlined cropping intentions, all test plot research, and overview of farm needs; also included detailed records of all test plot data and farm expenditures
5. Exchange of information with the project laboratory for effective use of crop, soil and water data
6. The performance of day-to-day farming operations

After assuming his post of May 3, 1972, the first farm manager familiarized himself with the dealers in farm equipment and researched local marketing facilities. The pieces of equipment purchased in May of 1972 were used in the farming operations associated with the agricultural productivity studies, and equipment operators were hired as needed throughout the remainder of that year.

Crop selections included corn as the main crop under wastewater irrigation and wheat or perhaps alfalfa in the border areas. Evergreens and hardwoods were to be grown in border and irrigation areas.

In the fall of 1972 and spring of 1973, specifications were written for farm equipment to be required for the expanding farm operation.

Farm Advisory Board

In accordance with a directive by the EPA, a farm advisory board was formed which consisted of faculty from Michigan State University with expertise in many areas of agronomy. The board was chaired by Dr. Ray Cook, Department of Soil and Crop Sciences, Michigan State University.

Members of the farm advisory board visited the site several times in 1973 and made several recommendations which ranged in scope from overall agricultural guidelines to specific herbicide-nutrient-soil precepts. This liaison was maintained with the WMS and farm management throughout the year.

Into 1974, Dr. Cook became the principal advisor to farming operations and was the member of the board who most frequently visited the site. His observations and recommendations were coordinated with project farming practices.

When Muskegon County assumed management of the project in December, 1974, the Farm Advisory Board was invited to WMS for a conference the purpose of which was to establish realistic crop yield expectations for the 1975 budget. That meeting was held. In 1975, the members did not reconvene because of the increasing experience of farm management and the relative absence of management problem areas. However, Dr. Cook has returned periodically and provided insights and advice on various aspects of the crop-soil picture.

THE FIRST MASTER FARM PLAN

Four goals were established.

1. Remove a maximum amount of nutrients from the irrigation wastewater by taking advantage of crop-soil interaction.

2. Follow soil husbandry practices to achieve maximum improvement of the soil annually.

3. Take advantage of research findings to enhance efficiency and productivity in farming operations.

4. Market the farm products for a profit.

It was the intention of the master farm plan to anticipate as fully as possible all aspects of crop management from initial crop selection to the final marketing. These categories of the plan are listed below and are briefly described, more or less chronologically, in the following pages. The categories are:

Master Farm Plan

Crop selection
Tillage operations
Lime and fertilizer
Insect control
Weed control
Planting
Harvest
Crop handling
Marketing
Other farm jobs
Agriculture - irrigation scheduling
Operations timetable and equipment needs

Crop Selection (Master Farm Plan)

Of the many factors influencing the selection of the primary crop for the wastewater management system, the most important were that the crop be compatible both with the goals of the system and with the soil-water-weather conditions at the site. Corn seemed to fit the picture well, and its advantages outweighed its disadvantages.

Advantages:

1. A tall foliar crop with good leaf area index, corn transpires much water.
2. Corn removes nutrients from the soil complex, particularly many of those in the WMS wastewater.
3. It requires relatively low machinery cost per unit area.
4. It is relatively easily established on recently cleared ground, moreso than would be small grains or a forage crop.
5. Corn has relatively low labor requirements.
6. It is adaptable to the cool, short growing season of Muskegon.
7. The grain is readily marketable for livestock.
8. Corn has good resistance to both soil and airborne insects.
9. It tolerates low pH soils.
10. It withstands early planting on loose sandy soils and becomes better established on such soils than many other crops.
11. In the event of delayed harvest, the nutrient composition of the seed does not change.
12. The unharvested crop residue adds large amounts of organic matter to the soil, thereby contributing to humus.

13. The expense of corn storage compares favorably to other crops.
14. An efficient user of available nitrogen, corn decreases the amount of nitrate leached during the growing season.

Disadvantages:

1. More hardy crops such as timothy and rye may grow better in fields of very coarse sand.
2. Corn has low toleration to soil saturated with moisture for extended periods of time.
3. The amounts of nutrients and water required by corn vary greatly with the age of the plant.
4. The height of the crop could create problems with irrigation equipment and its maintenance.
5. More soil erosion can occur with corn than with crops such as small grains or grass cover.
6. Corn requires yearly soil preparation, unlike many cover crops.

Tillage Operations (Master Farm Plan)

The purpose of heavy tillage is to pulverize roots and soil debris and to level the field surface. It was proposed that once an area had been cleared, the first tilling operation would employ heavy-duty agricultural discs of offset design with large diameter blades (either 61 or 66 cm) weighing in the range of 750 kg/m width. A disc of this size would require a tractor in the range of 112 to 168 power take-off kilowatts (150 to 225 hp). It was expected that much of the cleared land would be disced three or four times, and the last discing would incorporate lime and fertilizer, if needed.

Lime and Fertilizer (Master Farm Plan)

The early agricultural productivity studies would include determinations of pH and buffer pH on the soils of the site, and these data would be used for the assessment of lime needs.

The use of supplemental nitrogen would depend upon the levels in wastewater and the crop needs.

Insect Control (Master Farm Plan)

In initial operations, it was planned that Diazinon 14G would be applied for the control of wireworms, cutworms, rootworms, and other soil insects that attach to the emerging plant and to the kernel. It was to be applied during planting in 15 to 20 cm wide bands in the rows at the rate of 14 kg/ha. Isotox Seed Treater F or a similar product was to be used with the seed at an application rate of 5 g/kg seed. If a second insecticide was needed during the growing season for control of the corn borer, either Diazinon 14G at 8 kg/ha or EPN 2 percent at 12 kg/ha would be aerially applied. Control of other possible insect problems, such as billbugs and grasshoppers, was not spelled out.

Weed Control (Master Farm Plan)

Before planting, in areas where annual broadleaf weeds and grasses proliferated, Paraquat would be applied at a rate of 2.9 l/ha along with a spray mixture of Ortho-X-77 Spreader at 5 g/kg. After planting, it was suggested that the same areas receive Lasso at 3.5 l/ha and Aatrex at 0.6 kg/ha, or Aatrex alone at 2.2 kg/ha. Another post-planting alternative was to use the combination of Paraquat and Aatrex; 2.3 l Paraquat, 2.8 kg Aatrex and 0.6 kg X-77 Spreader would be combined with about 190 l water per hectare. Each chemical or chemical cocktail would be broadcast in a separate operation.

Corn Planting (Master Farm Plan)

The varieties of corn selected would be population tolerant, would have good standability and would be resistant to some of the common blights. The varieties would have a maturity range of 80 to 100 days.

The staggered planting schedule called for planting early and mid-season hybrids both early and late and the later hybrids to be planted early. It was thought that such timing would improve field dry-down, add time to the early combining season and allow for irrigation on those areas harvested first. If necessary, higher planting rates would be used to increase yields and offset poor germination which might be caused by too-early planting or inadequate seed bed preparation.

Row spacing was to be 76 cm. Besides being more efficient for light use, such narrow row spacing would shade the soil surface to inhibit weed growth.

Eight-row planters, 6.1 m wide, with both cyclo-air injection and no-till equipment, were specified.

Harvest (Master Farm Plan)

Harvesting would be with combines equipped with eight-row corn heads, with an estimated need of one combine per 610 hectares. Custom combining, if available locally, might be arranged if the equipment were adequate and approved by the farm manager.

Crop Handling (Master Farm Plan)

A survey of the grain dealers in the Muskegon area revealed that to meet the drying and storage requirements of the WMS farm, such a facility would have to be built on the site. Among the advantages would be cheaper drying costs, generally better service, minimal field time, increased effluent spray time, and more flexible marketability of the grain.

Figure 81 shows the recommended grain center schematic as it was later constructed.

The plan called for a dryer with a capacity of 15 to 25 metric tons of wet corn per hour. To achieve this large drying capacity without the expense of large commercial dryers, it was proposed that the hot corn be removed from the dryer and placed in bins through which cooling air would be circulated at a rate of 0.4 to 0.6 $m^3/min/m^3$ corn. From the aeration bins the cooled and dried corn would be transferred to overhead bulk bins for truck loadout.

Marketing (Master Farm Plan)

The crop was to be marketed through elevators in the Newaygo and Holland areas and potentially to other communities, depending upon market conditions. It was recognized that each year the market would fluctuate and would require decisions customized to current conditions.

Agriculture-Irrigation Scheduling (Master Farm Plan)

The best estimates for the agriculture-irrigation program are summarized in Table 91. It was

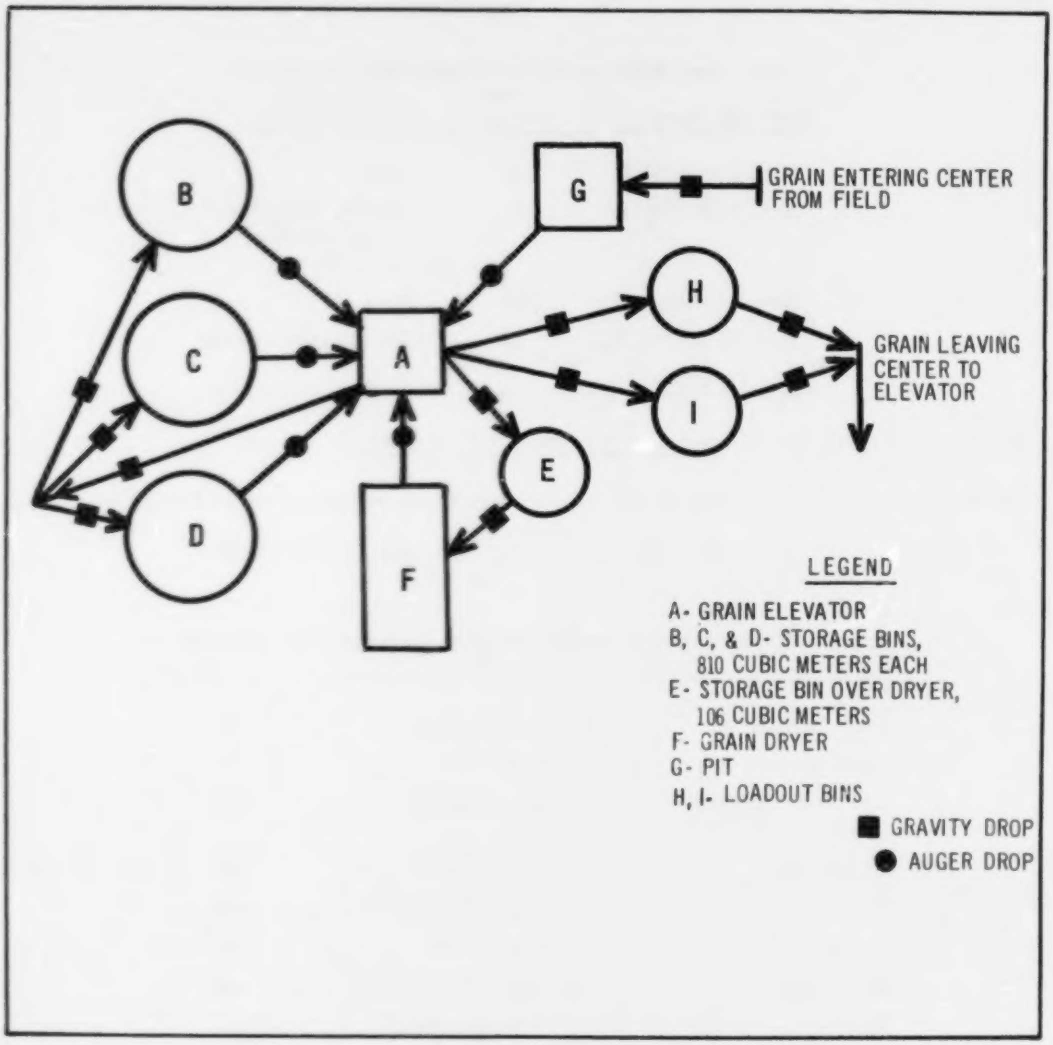
B
C
D
A
G
GRAIN ENTERING CENTER FROM FIELD
H
I
GRAIN LEAVING CENTER TO ELEVATOR
E
F
LEGEND
A- GRAIN ELEVATOR
B, C, & D- STORAGE BINS, 810 CUBIC METERS EACH
E- STORAGE BIN OVER DRYER, 106 CUBIC METERS
F- GRAIN DRYER
G- PIT
H, I- LOADOUT BINS
■ GRAVITY DROP
● AUGER DROP

Figure 81. Grain center schematic

believed that with this timetable – allowing for the heavy irrigation rates during the summer – a total of 165 cm of wastewater could be applied on farmland for the year. The schedule allowed for field operations in the spring and fall, during which some part-time irrigation might be done. And it allowed about two days per week as non-operating time which might be required because of rainfall or maintenance problems.

Table 91. AGRICULTURE-IRRIGATION OPERATIONS
(Master Farm Plan)

Irrigation dates, 1973	Percent of time	Agriculture operation time
April 1 to April 15	100	None
April 15 to May 19	50	Tilling, lime, fertilizer, planting, herbicide
May 19 to Sept. 21	100	None
Sept. 21 to Oct. 17	30	Drydown for harvest
Oct. 17 to Nov. 15	100	None

Operations Timetable and Equipment Needs (Master Farm Plan)

The best estimates of time requirements for the various farm operations are in Table 92.

Table 92. TIMING OF AGRICULTURAL OPERATIONS[a]
(Master Farm Plan)

Operation	Time period	ha/day
Heavy discing	8 days in April	71
Heavy discing	14.5 days in May	71
Lime and fertilizer application	10 days in April	105
Chisel plowing	7 days in April	81
Discing	7.5 days in May	16
Planting	13.2 days in May	77
Harvesting	5.3 days in September	45
Harvesting	17 days in October	45
Spraying (custom applied)	14 days in May	72

[a] Timing based on the availability of equipment shown in Table 94 and performance expectations shown in Table 93.

Of the 1,000 hectares expected to be cropped in 1973, about 450 ha were to be newly cleared land, and it was predicted that this 450ha would require three discings – two before application of lime and fertilizer, one after. The other 565 ha were to be chisel-plowed once and disced. Based upon the assumption that the above treatment would be adequate for the 1,000 hectares, the performance expectations for the growing season were estimated and are tabulated in Table 93.

Table 93. EQUIPMENT PERFORMANCE EXPECTATIONS
(Master Farm Plan)

Field operation	Number of units	Implement width, meters	Assumed efficiency, percent	Field speed, km/hr	Hectares to cover	Operation days
Chisel plowing	(2)	7.30	85	8.00	565	7
Heavy discing	(2) (1)	6.10 3.70	85	7.20	1800	23
Light discing	(1)	4.00	85	6.40	120	8
Planting	(3)	6.10	70	7.20	1000	13
Combining	(2)	6.10	70	6.40	1000	22

The number of days available for field work – or operation days – is influential in determining specific equipment requirements. It was felt that in the case of 22 days for harvest, for instance, the number might be reduced by leasing or custom-hiring one additional combine. Similar adjustments might be necessary for other operations. The complete listing of major farm equipment as envisioned in the master farm plan is in Table 94.

Table 94. AGRICULTURE EQUIPMENT FOR CROP YEAR 1973
(Master Farm Plan)

Description	Number to be needed
Tractor, 168 kilowatt (225 hp)[a]	2
Tractor, 119 kilowatt (160 hp)	2
Tractor, 93 kilowatt (125 hp)	3
Tractor, 60 kilowatt (80 hp)	1
Tractor, Industrial Loader, 20 kilowatt (27 hp)	1
Lime and fertilizer spreader	2
Chisel plows, two 7.3 m, one 4.3 m	3
Offset discs, three 6.4 m, one 3.7 m	4
Corn planter, 8-row (76 cm)	3
Regular disc, one 4.0 m	1
Combine, 8-row	1 (or 2)
Grain wagon	8
Pickups	3
Trucks	2
Grain handling center	1 complete
Grain drill (for seed border and grass area)	2

[a] All power ratings for tractors are based upon drawbar performance.

Other Farm Jobs (Master Farm Plan)

Farm personnel and equipment were to be used for site beautification, including weed control around the perimeters of the lagoons and other designated areas of the site. The approach to weed control would be mechanical where feasible and chemical in areas inaccessible to cutting devices.

At times of slowdown in farming operations, periods would be devoted to alleviation of insect problems and to enhancement of overall aesthetics.

Additional site clearing and light dozer work would be done by blades mounted on agricultural tractors.

A full maintenance program would be instituted which would focus upon problem identification and maintenance of equipment and agricultural land. A shop with a full-time employee in this area was specified.

1973 FARM ACTIVITIES

The still disrupted condition of the WMS farmland in 1973 in large measure prevented implementation of the master farm plan. Because clearing operations were behind schedule, only 610 ha were put under crop production, and, of these, only 53 ha were irrigated. The resulting corn harvest, which was mostly from the irrigated fields, amounted to 736 metric tons, or an average yield of 1.2 metric tons/ha. The corn was sold to a grain elevator in Newaygo, Michigan.

The first opportunity to farm most of the WMS farmland came in 1974.

1974 FARM ACTIVITIES

Overview

The total acreage put into crop production in 1974 amounted to 1200 ha of newly cleared land plus 690 ha of land previously cropped. Of the new acreage, a third was not cleared until after the normal planting period, so these fields were quickly planted with a minimum of field preparation.

The condition of the fields after clearing was terrible. Debris ranging from concrete chunks and bedsprings to limbs, stumps and roots plagued operations from tilling to harvest and caused breakdown or lowered efficiency in virtually all pieces of equipment. Multiple discings, when time permitted, eventually achieved a fairly even planting surface and an adequate seedbed.

Equipment efficiencies were reduced about 50 percent in most cases. Though ground speeds of 5 km/hr were seldom exceeded, many breakdowns occurred, particularly in the case of the more delicate pieces such as planters and combines. Efficiency further suffered because circular fields are more time-consuming than rectangular fields due to irregular lengths of rows, overlapping of operations and increased turning times.

The difficulties did not end with field trash. Because of unfavorable weather and field conditions, many of the fields were planted very late, resulting in a failure of the corn to reach maturity before the first killing frost in the fall. This killing frost in 1974 was one of the earliest on record in the Midwest. Corn yields were severely depressed, and that corn which was harvested had a high moisture content. Even before the frost, the climatic conditions were less than ideal; the corn crop received 300 to 400 growing degree days (GDD) less than normal. On that third of the planted acreage where irrigation was not possible, a dry early summer critically hampered corn growth. In the areas under irrigation, problems with plugging of the nozzles in the irrigation spray bars created localized dry areas of poor growth. And with the mode of application of fertilizer being via the irrigation water, a third of the acreage received no irrigation – and therefore no fertilizer – until the crop was nearly mature and severely deficient in nutrients.

In 1974 the wastewater in the storage lagoons was very high because of heavy rains in the early spring and because of delays in the assembly of the irrigation rigs. Consequently, those fields with functional rigs received extraordinary volumes of irrigation water, frequently without regard to crop needs. The resultant saturation in low areas and in locations of heavier soils caused severe crop damage. Only the very sandy areas tolerated the heavy applications.

Wheat 1974

Wheat was planted as a cover crop on 110ha of marginal land outside of the irrigation circles. These areas were disced in August and September to prepare an adequate seedbed, and fertilizer was applied to a portion of the acreage. See Appendix G, Figure 1.

After the fly-free date, September 15, and before the corn harvest at the end of the month, the wheat was planted in rows 18 cm apart with a small grain drill pulled by a utility tractor.

The wheat seed was treated Ionia seed and was planted at a rate of 94 kg/ha.

At maturity, the crop was considered to be satisfactory.

However, it was recommended that in the future more fertilizer be applied both as a starter in the fall and as additional nitrogen in the spring. Greater population density was suggested in order to discourage weed competition. More land should be cleared for wheat in 1975 and methods of effective weed control investigated.

Corn 1974

Tillage and Planting –

Spring tillage began with snow on the ground in early March, and before planting in the first two weeks in June, many fields were disced as many as five times. Tillage was done by six four-wheel-drive tractors pulling two large chisel plows and four heavy duty offset discs from 6 to 8 meters wide. Some finish discing was done with two lighter discs and utility tractors.

Time of planting ranged from April 23 to June 15, 1974, proceeding as land clearing and weather permitted.

Planting was done on about 1900 ha by eight cyclo-eight-row, 76 cm corn planters pulled by utility tractors. One of the planters was equipped with a fertilizer attachment. Seed placement was excellent considering the adverse field conditions. Granular insecticide was applied.

The seed corn included varieties from Trojan, Funks, Pioneer, Cowbell, Acco, Jacques, Northrup King, and Teweles. Specific variety information, dates of planting and field locations may be found in Appendix G, Table 2. The quality of the seed corn was generally good and the germination acceptable.

Herbicide Program 1974 –

Pre-emergent herbicide was aerially applied between April 3 and June 3 while field preparations were in progress. Post-emergent herbicide was ground applied between May 30 and July 3, 1974, with two utility tractors and two tanks, one trailer-type of 380 liter capacity and one saddle-mounted of 760 liter capacity. Ground application was done only on areas where aerial coverage was inadequate. See Appendix G Table 3.

Lasso and Aatrex were aerially applied. Aatrex plus a crop oil surfactant was ground applied as a post-emergent herbicide. In addition, some Sutan was ground applied.

Weed control was considered generally good in light of the volume of irrigation water and the weed seed accumulation on idle ground. A few dense patches of nutsedge and quackgrass persisted. It was noted that ground applied herbicide was particularly effective in post-emergent problem areas when, after its application, irrigation was discontinued for a few days. Herbicide aerially applied prior to corn emergence failed to control weeds in several areas, especially after heavy irrigation.

Fertilizer Application 1974 –

Applications of commercial granular fertilizer were made between April and August, 1974, with the greatest amounts applied in July during peak corn need. Two fertilizer and lime spreaders were pulled by utility tractors to cover most fields, and, in some cases, the fertilizer was metered into the irrigation water at the pump. The latter procedure was resorted to during the growing season after starter applications proved inadequate. Because granular fertilizer is not easily solubilized and not easily metered uniformly, a grossly uneven application of fertilizer resulted.

The amounts of N-P-K applied to each field in kg/ha may be found in Appendix G, Tables 4-9.

It is known that almost all of the sandy soils contained negligible amounts of nutrients. Wastewater irrigation was not applied to most acreage until the crop was nearly mature, so the corn crop that was harvested – and it was small – may easily be attributed to fertilizer. See Appendix G, Table 8 for irrigation by circles. Corn was harvested only from areas of adequate irrigation and fertilizer.

Corn Harvest 1974 –

Harvest began October 1 and extended through December 4 because unsatisfactory weather and high grain moisture impaired field efficiency. Equipment for the harvest included two WMS self-propelled combines with eight-row corn headers and two other combines by a custom operator, one identical to the WMS model and one smaller self-propelled model with a four-row head. For grain transport to the grain center, two trucks of 2.3 metric ton capacity, four utility tractors and eight grain wagons were used. See Figures 82 and 83 below.

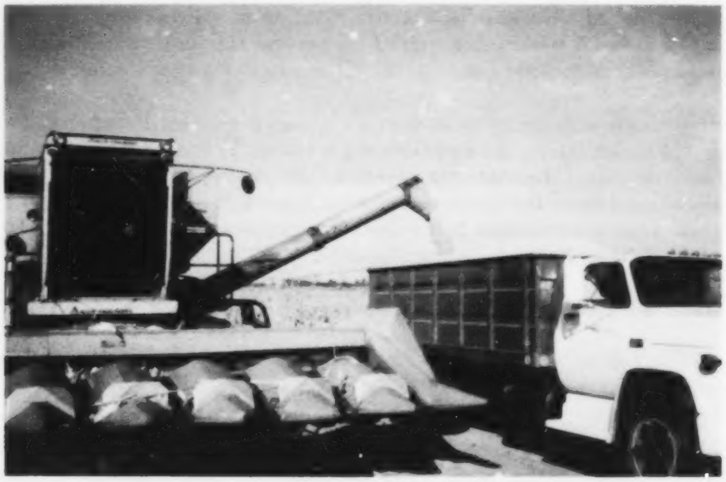

Figure 82. Eight-row combine harvesting corn in the field

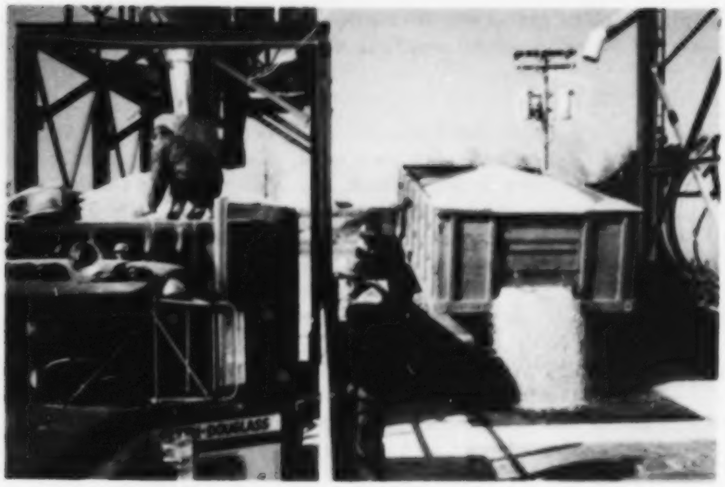

Figure 83. On the right, corn from the field being unloaded at the grain center, and on the left, dried corn being loaded for shipment

Wet corn yield varied from 0 to 5.3 metric tons per hectare or 0 to 3.5 metric tons per hectare dry corn. Moisture content ranged from 22 percent to 50+ percent and averaged 31 percent. Total wet corn harvest for the year of 1974 was 5330 metric tons, or an average yield of 2.8 metric tons per hectare. Converted to No. 2 marketable corn (15.5 percent moisture content and 721 kg/m^3 test weight), this yield reduces to 3380 metric tons or 1.8 metric tons per hectare.

The problems associated with the 1974 harvest were many. For details of buried electrical cable faults, delays in rig construction and irrigation rig mechanical breakdowns, see the section on operations and maintenance. Low ear placement on the stalks, trashy field conditions and extremely wet grain slowed down the combines. Drying time was so long that loads of grain bottlenecked at the grain center, sometimes being delayed to spoilage. And those loads that did dry shrunk and cracked, further diminishing grain quality.

The crop was sold to the Newaygo Elevator, Newaygo, Michigan.

For details of planting dates per field, see Appendix G, Table 2, and for data on corn yield and moisture content, See Appendix G, Table 9.

Recommendations –

After the experiences of 1974, the following procedures were recommended:

- Plant corn so that fields in the same general vicinity mature at the same time, thereby saving combine travel and increasing handling efficiency.

- Field preparation should be improved with multiple discings and, if necessary, by hand-removing gross debris.
- Corn planting equipment should be mechanically as simple as possible because of incidence of breakdown.
- Planting should be begun as early in May as weather permits to guard against early frost kill.
- Weed control should be improved by better coordination of aerial applications of herbicide with irrigation; when possible rigs should be shut down for two days after herbicide application.
- Soluble fertilizer should be added to irrigation water for uniform application.
- Operation of combines much after dark should be discontinued because of lowered efficiency.

Grain Center 1974 –

As recommended in the master farm plan, the grain center was constructed in time to receive and dry most of the 1974 corn crop. The dryer was operated 24 hours per day. Although storage facilities were available at the center, all of the grain was shipped after drying.

Fall Tillage 1974 –

Fall discing continued through foul weather from harvest until the ground froze. Because these tillage operations were not completed, there was a great abundance of volunteer corn in 1975.

1975 FARM ACTIVITIES

Overview

One of the most significant reasons for the success of the 1975 corn crop was the favorable weather for the duration of the growing season: a fairly dry spring, warm summer and dry fall. The first-frost-date was average, and the number of growing-degree-days was slightly above average.

Another important factor was that lagoon water levels were lower in 1975 than in 1974, so there was more discreet use of irrigation water with focus upon plant requirements. The only spots of flooding were in low areas of low permeability or plots serviced by defective rigs – such as those with persistent nozzle plugging – or areas where dramatic differences in soil type exist. In general, crop water distribution was uniform and consistent with crop needs.

Field conditions had improved markedly from 1974 with the exception of the remaining stumps and large wood fragments which again damaged equipment and hampered operations. But general leveling and rotting of smaller debris made for more satisfactory farming conditions, and field equipment speeds rose from five or less to six or eight km/hr.

In some circles, especially circle 40, much of the soil is devoid of organic matter. These sandy, droughty areas are in large part unproductive; the illustration in Figure 84 shows circle 40 in July, 1975, when the corn was at the tasseling stage. It is on such areas that sludge removed from the aeration should be spread.

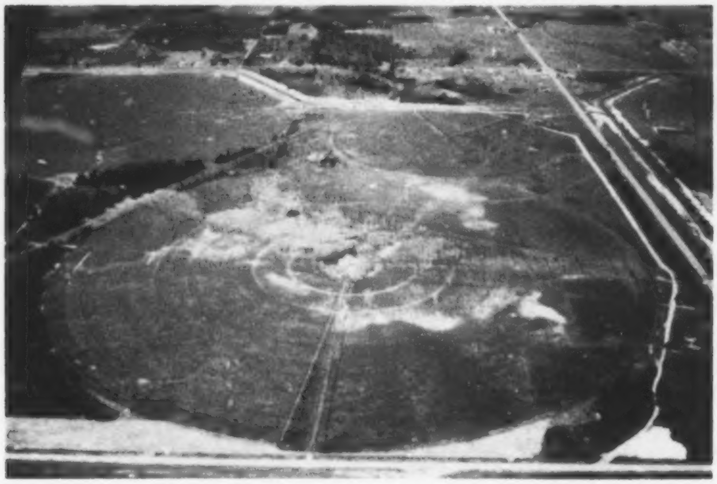

Figure 84. Spotty growth on circle 40 which has a soil mixture of sand and muck

Wheat 1975

Harvest –

Wheat harvest was completed in the last week in July and first week of August, 1975. The crop was harvested with a self-propelled combine equipped with a four-meter grain head and cutter bar. The grain was transported to a local elevator by two grain trucks, each of 2.3 metric ton capacity.

The wheat yield was small and of poor quality. Because there was insufficient fertilizer and little rain, the wheat was dominated in many areas by weeds. Every effort was made to harvest all the crop irrespective of the poor condition of the stand. The grain marketed contained little fine material and had sufficiently low moisture that dockage was avoided in most cases.

A total of 68.6 metric tons was harvested from 110 ha, for a yield of 0.63 metric tons per hectare. The average moisture content was 14.1 percent and ranged from 12.7 to 16.9 percent. The average test weight was 715 kg/m^3 and ranged from 682 to 734 kg/m^3. The average fine material content was 2.0 percent and ranged from 1.0 to 5.0 percent.

The wheat crop was sold to the Kent City Farm Bureau, Kent City, Michigan.

It was recommended that for 1976 seeding rate be increased by a third and that both a starter and a spring fertilizer program be implemented.

Tillage and Wheat Planting 1975 –

In preparation for wheat planting, discing with utility tractors was done on 178ha and, of these, 20ha were plowed before discing with a six-bottom plow and utility tractor. A generally good seed bed was prepared. See Appendix G, Figure 2 and Table 10.

To all wheat acreage, about 139 kg//ha of 5-10-30 fertilizer was applied and disced in prior to planting. In one field where the evidence indicated the soils could hold the nutrients, 270 kg/ha were applied.

Treated certified Ionia seed was planted with two grain drills (17 and 18 hole) pulled by utility tractors at a rate of 126 kg/ha between the 15th and 29th of September, 1975.

Corn 1975

Tillage and Planting –

Tillage operations extended from early April to the end of May, with 90 percent of the fields completed by mid-May, 1975. Discing was done from once to three times with four four-wheel-drive tractors pulling matching heavy-duty offset discs, six to eight meters wide. Field conditions were vastly improved, and the finished smooth seedbed contributed greatly to the improved efficiency of all field operations. Time and manpower requirements were reduced from 1974. Downtime of tillage and planting equipment was also significantly reduced by the newly created maintenance department. The few breakdowns of tillage equipment were attributed to wood chunks and to attrition.

Time of planting was from May 1 to May 30, 1975, with 96 percent finished the first three weeks.

A total of 1820 hectares were planted with up to five cyclo eight-row, 76-cm planters pulled by utility tractors. The seed corn was purchased from Trojan, Pioneer, Jacques, Funks, and other Michigan dealers and was, in general, of poor quality because early frost the preceding year hindered germination. Some varieties were so small as to create mechanical problems with the planters.

Planting was early for good expected crop maturity and seed placement was uniform.

Specific information can be found in Appendix G, Table 11.

Herbicide Program 1975–

Lasso and Aatrex, pre-emergent herbicides, were aerially applied from April 26 to May 24, 1975, as field preparation was in progress, and Aatrex with crop oil surfactant was ground applied between June 2 and July 8, 1975. Sutan was herbigated in one field. See Appendix G, Table 12.

For ground application, two pairs of saddle-mounted 760 liter spray tanks on utility tractors were used.

Except for a few areas of quackgrass and broadleaf weeds, weed control was generally good. As in 1974, the post-emergent application was most effective when followed by two days of shutdown of irrigation. Because the post-emergent herbicide must be ground applied with low spray bars and cannot be continued after corn achieves knee-height, the time allowed to cover the entire acreage was restrictive.

The aerially applied pre-emergent herbicide was followed by heavy irrigation and, as in 1974, was less than adequate.

Herbigation did not produce any noticeable effect on the weed population.

Fertilizer Application 1975 –

Liquid fertilizer was injected into irrigation wastewater from July 3 to August 18, 1975, with most being applied during peak need in July. A tractor-mounted PTO drive pump was used to meter liquid fertilizer through a PVC header at one of the irrigation pumping stations. Four tanks of 1890 liter capacity each were towed to the pivots of the irrigation rigs for additional application.

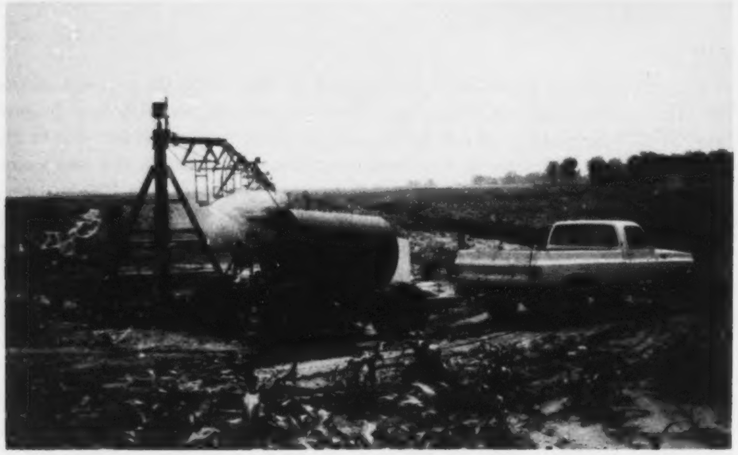

Figure 85. Nurse tank at the pivot of an irrigation rig for fertilizer injection

The only commercial fertilizer applied to 54 fields of corn was 28 percent urea-ammonium nitrate* in rates ranging from 0 to 100 kg/ha depending on the volume of wastewater that could be irrigated and on plant needs. Rates per field in kg/ha are listed in Appendix G, Table 13. This approach worked well. The liquid was easily mixed with the wastewater and provided a gradual but very uniform application. The response of the corn crop was remarkable when the amount of injected nitrogen balanced the rest of the nutrients in the irrigation water. Only those fields with a muck layer received little wastewater and therefore little nitrogen. Amounts of N, P, K applied in wastewater per circle are in Appendix G, Tables 14, 15, and 16.

Cultivation 1975 –

For control of volunteer corn and weeds two eight-row-rear-mounted cultivators with two utility tractors were tried on five fields between June 10 and July 3, 1975.

Although most of the unwanted plants were killed, cultivation did not provide the desired control unless weeds were very small. There was a tendency, also, for the cultivator to catch pieces of trash, and before the pieces could be removed, damage was done to plants.

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*359 kg ammonium nitrate, 277 kg urea dissolved in 273 liter water

Cultivation required more time and manpower and achieved less than the herbicidal approach. Specific field locations and dates of cultivation are in Appendix G, Figure 3.

Corn Harvest 1975 –

Time required for harvesting corn was 37 days between September 29 and November 5, 1975, and the equipment employed was identical to that used in 1974.

Wet corn yield ranged from 1.9 to 6.5 metric tons per hectare with a moisture content from 18.5 to 27.8 percent. Dry yield equivalent ranged from 1.8 to 5.6 metric tons per hectare. Total weight harvested in 1975 was 7,490 metric tons, giving an average yield of 4.1 metric tons per hectare and average moisture content of 23 percent. Converted to Number 2 marketable corn – at 15.5 percent moisture and 721 kg/m^3 test weight – the harvest totaled 6,860 metric tons with an average yield of 3.8 metric tons per hectare. See Appendix G, Table 17.

The 1975 corn harvest operations proceeded smoothly, largely due to ideal weather and relatively dry corn. Combine work shifts of 18 hours per day were later cut to 12 hours to increase manpower efficiency. Two combines together harvested 1270 metric tons of corn per day. Very little corn was left in the field because of the improved field conditions and the higher placement of the ears on the stalks, facilitating more efficient combining.

The problems associated with the harvest were primarily logistical. When corn yield was abundant and the fields were remote from the grain center, the grain hauling and drying facilities became critically overloaded. As many as 3,000 metric tons of wet corn backed up behind the dryer at one time. It is often not possible for two trucks to keep pace with the two combines plus the custom operator, so eight wagons were used to supplement hauling loads to the grain center. Ground conditions were still not good enough for protracted periods of night work.

The 1975 crop was sold to grain dealers in Chicago, Illinois, Newaygo, Michigan, Zeeland, Michigan, and to a turkey farmer in Zeeland, Michigan.

Fall Tillage 1975 –

To inhibit growth of volunteer corn, all 1800 ha were disced as soon as possible after harvest with a new swing-type disc and a new articulated, 168 kilowatt (225 hp) four-wheel-drive tractor. This style of disc has two independent sections which, when opened, cover nine meters, tilling about six ha/hr. Fall discing was finished by November 24, 1975. See Figure 86.

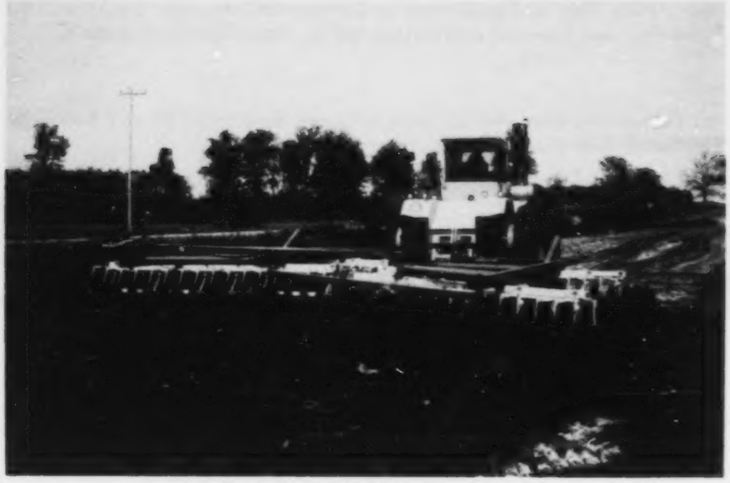

Figure 86. Swing-type disc in tow by a four-wheel drive tractor

Other Crops 1975

Rye –

The crop of Balboa rye which was seeded in two of the sandiest fields in the fall of 1974 to utilize wastewater nutrients and to build up humus was heavily irrigated and allowed to mature. The crop was disced under in mid-September, 1975, and allowed to reseed itself. The mature crop was re-disced in the spring of 1976.

Soybeans 1975 –

At the end of May, SRF 100 soybeans were planted on 13 ha at a rate of 63 kg/ha. In spite of the use of herbicide and cultivation, broadleaf weeds dominated the field. Weed cover and the effects of irrigation combined to delay crop maturity, and frost severely damaged the plants. The soybeans were low to the ground on fairly rough terrain and were therefore difficult to combine. The yield was 690 kg/ha, and the moisture content was 16 percent.

The crop was sold to a farmer in Ravenna, Michigan.

Alfalfa 1975 –

Vernal alfalfa was planted on June 1 on seven hectares of very sandy field. High wind and water erosion caused crop failure. A cover crop will have to be planted with alfalfa plots and the soil pH raised significantly before a good crop can be realized.

Recommendations

Based upon the farming experiences of 1975, the following recommendations were made:

- Before ordering seed corn, a count per unit volume should be obtained to prevent errors in ordering due to exceptionally small seed.
- With improved field conditions, the use of a conventional disc for tillage – rather than the gross heavy-duty models – would produce a smoother seedbed and contribute to field efficiency.
- Cultivation should be discontinued except in trash-free fields for the control of volunteer corn only.
- The nurse tanks of liquid fertilizer should be placed at the pivots of the fields receiving the least amount of irrigation and all other fields should receive their nitrogen injection at each of the two pumping stations. Also a PVC header fed by an accurate metering pump should be placed across the channel ahead of the pumps.
- The grain center should be expanded, and methods of expediting grain transfer from the field should be investigated.
- Operating combines at excessive speed should be discouraged because of increased crop damage and grain loss.
- Work shifts should not exceed 12 hours per day because of noticeable decrease in field efficiency due to equipment malfunction and operator fatigue.

Grain Center 1975

By operating 24 hours per day, the grain center performed well in processing 7490 metric tons of corn. Even with the depressed grain moisture content, the capacity of the dryer to receive the volume-flow of grain from the fields was sometimes exceeded. It was clear that dryer capacity should be increased.

For marketing purposes, about 1800 metric tons of corn was held in the grain center storage facilities for sale the following spring.

ANALYSES OF FARM DATA

Corn yield has approximately doubled each year. This was due to increased acreage under irrigation and in solution of a multitude of mechanical rig problems in combination with gradually improved field conditions. Uniform fertilizer distribution was not achieved until 1975, and significant increases in the efficiency of all field operations from tillage to drying were first realized in that year. Also in 1975, lagoon wastewater levels permitted the dispensing of irrigation in accordance with crop needs.

Table 95. COMPARISONS OF AREAS PLANTED, AREAS IRRIGATED, CORN MARKETED, AND CORN YIELDS FOR YEARS 1973, 1974 AND 1975

	Year		
	1973	1974	1975
Area planted to corn (hectares)	607	1900	1900
Area irrigated (hectares)	53	1270	1900
Corn marketed (metric tons)	737	3380	6860
Corn yield (metric tons/hectare)	1.2	1.8	3.8

Correlated Comparisons

Many factors contributing to the corn crop in 1974 and 1975 were correlated, and the results are tabulated below in Table 96. All comparisons were made between individual fields.

Table 96. 1974 - 1975 CORRELATED COMPARISONS

Factors correlated	Appendix G, Table number	"r" value
1974 corn yield - variety maturity	9, 2	0.10
1975 corn yield - variety maturity	19, 11	0.10
1974 corn yield - water irrigated	9, 8	0.29
1975 corn yield - water irrigated	17, 18	0.48
1974 corn yield - available nitrogen	9, 5	0.20
1975 corn yield - available nitrogen	17, 14	0.61
1974 corn yield - available phosphorus	9, 6	0.27
1975 corn yield - available phosphorus	17, 15	0.50
1974 corn yield - available potassium	9, 7	0.17
1975 corn yield - available potassium	17, 16	0.47
1974 corn yield - planting date	9, 2	-0.45
1975 corn yield - planting date	17, 11	-0.61
1974 corn yield - harvest date	9	-0.42
1975 corn yield - harvest date	17	-0.54
1974 corn yield - GDD	9, 19	0.41
1975 corn yield - GDD	17, 19	0.15
1974 corn yield - percent moisture content	9	-0.14
1975 corn yield - percent moisture content	17	0.26
1975 corn yield - nozzle plugging on Rubicon soil	17, 20	-0.44
1974 moisture content - corn maturity	9, 2	0.24
1975 moisture content - corn maturity	17, 11	0.97

No linear correlation between corn yield and maturity was found for the corn crops of 1974 or 1975. Amount of yield and amount of irrigation were better correlated in 1975 than in 1974, as was yield and amounts of nutrients. The severity of the weather in 1974 probably ruled out several such correlations. But for both years there was a fairly negative linear correlation between yield and planting date, supporting the idea of earliest possible spring planting. This is reinforced by a similar relationship between harvest date and yield.

The negative correlation between nozzle plugging on the sandy Rubicon soil and crop yield was expected.

Moisture content would predictably correlate well with corn maturity, as it did in 1975, but the problematic weather of 1974 is again the reason for this low "r" value.

"t" Statistic Comparison Results

A paired "t" test was used to find significant differences between the 1974 and 1975 seasons.

Table 97. 1974 AND 1975 EVALUATION OF SIGNIFICANT DIFFERENCES, GROWING SEASONS

Factor	Data found in Appendix G, Table number	Significant changes from 1974 to 1975	"t" values	
			t_{cal}	t_{95}
Corn yield	9 & 17	Increase	-14.5	1.70
Monthly GDD	20 & 21	Increase	-23.6	1.80
Grain moisture content	9 & 17	Decrease	11.3	1.70
Rainfall	21	None	1.20	1.90
Lime deficit	2	Decrease	5.00	1.70
Planting dates	2 & 11	Decrease	1.90	1.70
Harvest dates	9 & 17	Decrease	7.40	1.70
Irrigation	18 & 5	None	1.50	1.70
Crop available nitrogen	14 & 6	Increase	- 5.20	1.70
Crop available phosphorus	15 & 7	Increase	- 5.80	1.70
Crop available potassium	16 & 19	None	- 0.60	1.70

A comparison between 1974 and 1975 crop factors revealed no significant changes in monthly rainfall, irrigation rates, or potassium addition. Increases were seen in corn yields, growing degree days, nitrogen supplemented, and phosphorus received by the crop. The dates of planting and harvest were significantly earlier in 1975. The amount of lime needed by the soil in 1975 decreased and grain moisture content showed a measurable decline also.

"F" Statistic Comparison Results

Overall differences were tested using analysis of variance.

Table 98. 1974 - 1975 "F" STATISTIC COMPARISONS

	Significant difference		"F" values	
Factor	Group	Yes or No	F_{calc}	F_{95}
1974 corn yield	Soil series	No	0.8	2.8
1975 corn yield	Soil series	Yes	3.0	2.8
1974 corn yield	Corn varieties	No	1.8	2.6
1975 corn yield	Corn varieties	Yes	4.1	2.2
1975 nozzle plug	Soil series	Yes	5.9	2.8

In Table 98, whereas analysis of variance showed no significant difference in yield in 1974 when compared with either soil series or corn varieties, in 1975 a significant difference was found in both cases. Again in 1974 weather introduced such a cumbersome variable that few significant differences emerged. Nozzle plugging, as expected, showed a significant difference between soil types.

Means and standard deviations for all farm data can be found in Appendix G, Table 22.

FARM MANAGEMENT OVERVIEW AND RECOMMENDATIONS

Changing Trends

For the early farming operations, equipment selection was based upon ability to perform under the crudest field conditions. As ground surface conditions have gradually improved, small rugged tillage units have been replaced by larger, more efficient models, so that two discs now outperform the original six.

Harvest equipment originally purchased was well suited to site demands and has been replaced with identical models. The fact that more corn is being handled by this equipment each year may be attributed to the improvements in field conditions.

Although the grain center has been generally adequate to the production levels thus far, appropriate modifications in its storage and drying capacities will be needed if the increasing trend in grain yield continues.

Cropping of Border Areas

Over 400 ha of unforested land outside of irrigation are not used at WMS. Plots were tested for the suitability of wheat to investigate the crop potential as a marketable grain crop while simultaneously serving to control weeds and improving site appearance. Although the 1974 yield was not great for 110 ha, the planting did accomplish the secondary goals and, in addition, improved the soil. In 1975, the 178 ha devoted to wheat was better attended and gave some indication that this crop may be developed into a more significant WMS resource. A larger wheat acreage has been planned for 1976-1977.

Herbicide Program

A gradual but dramatic change has taken place in the methods of weed control at the project. The hazardous field conditions and large acreage forced aerial application of herbicide almost entirely during the initial farm operations. In 1975 emphasis shifted to ground application of herbicide, particularly in areas inadequately covered by the aerial treatment. The 1976 herbicide plans are to exclusively ground apply the chemicals, for this approach is more effective on sandy soils. The increasingly smoother field conditions allow for more efficient ground application, and more spray equipment has been purchased.

Fertilizer Programs

Potassium and Phosphorus –

Because sandy and mucky soils are very low in available potassium and phosphorus, these two nutrients were initially spread on the fields to grow corn. The wastewater, however, contains large amounts of these elements, and the soil has started to accumulate residues of K-P. These nutrients are no longer added to heavily irrigated fields, but those fields receiving very little irrigation and the wheat areas outside of irrigation do need potassium and phosphorus. They are being managed accordingly.

Nitrogen for Corn –

As soon as wastewater became available for irrigation, it was evident that the nitrogen content of the irrigation water was inadequate to supply the needs of corn. The early approach of spreading granular N along with P-K gave way to metering granular nitrogen into irrigation ditches. Because of mixing problems and non-uniform application, liquid nitrogen injection into the ditches was tried. Mixing was good and a steady feed of low concentration nitrogen could be applied to a large acreage with minimum leaching.

For 1976, nitrogen management is to include ditch injection for sandy fields. For fields of low tolerance to heavy irrigation, injection of more concentrated doses at the irrigation rig pivot will provide an adequate supply. Either method can supply 1.1 kg/ha/day nitrogen, a level which was demonstrated in the agricultural productivity studies to not leach significantly from the soil profile.

Nitrogen for Wheat –

Prior to 1975, nitrogen was not consistently applied to wheat. For the 1975-1976 crop, starter fertilizer was applied in the fall with additional nitrogen added in the spring, resulting in a doubling of the 1974-1975 yield. Nitrogen management in sandy soils and its optimum application for wheat at WMS is under continued study.

Water Management

In 1975, the results of good water management and cooperative irrigation were reflected in dramatic increases in crop yields. It is not expected with present flow rates that high lagoon water levels should occur again. Experiences over three years allow for far-sighted advanced planning for both crop needs and wastewater renovation.

Those mechanical irrigation problems which resulted in areas of drought are being solved. Uniform and timely water application is already a reality over the vast majority of the irrigated land.

Drainage systems are being studied and redesigned in an effort to optimize more of the available land for wastewater renovation.

Seed Selection

The early agricultural productivity studies included more than 100 corn varieties in a survey to find these hybrids most productive in this environment. Although those trials were complicated by irrigation irregularities, it was possible to screen out some desirable hybrids. In 1975 with the old mechanical defects corrected and field conditions vastly improved, it was possible to plant large acreage to each of several varieties. And with staggered maturities, not only does the selection process continue for corn productivity and suitability, but the probability of crop failure is also reduced. It is the intention of management to continue this selection process in hopes of learning about – and profiting more from – corn.

Crop Maximization

The major recommendation of the WMS farm management is that every reasonable effort should be made to maximize corn crop production. A healthy crop translates into maximum uptake of nutrients applied to the soil in the wastewater renovation process, and by stressing uniformity of irrigation, sound crop practices and excellence of plant stand, high quality water is achievable.

Research

With research facilities and crop land in juxtaposition at WMS, the relationship between research findings and farm management has been especially intimate. The early agricultural productivity studies provided essential guidelines for almost all start-up farming operations, and those findings still influence current farm management decisions. The importance of agricultural research cannot be overemphasized for the discovery of best alternatives when juggling the complex individual demands of crop, soil, and wastewater, while always seeking the primary objective of nutrient recovery.

A case in point is the role of nitrogen. Easily leached, it is the most critical element in both corn growth and water pollution. Nitrogen research at this project has educed from soil of almost pure sand, corn yields of unexpected magnitude; this has been done without returning significant amounts of nitrogen to surface waters, and it has been done within the framework of cost-effective water renovation.

SECTION 12

SOCIO-ECONOMIC STUDY*

SCOPE AND INTENT

The evaluation of the socio-economic impacts of the Muskegon Wastewater Management System (WMS) was made within the context of the planning and policy program that initiated and implemented the project. The WMS was seen by the local planners and policy-makers as a primary investment in the general development and improvement of Muskegon County. It was to serve as a first step in the overall community program, aiding in improving environmental conditions in the region and acting as a direct catalyst to water-oriented development by providing tertiary treatment for wastewater. The expected economic efficiency, high level of treatment performance and flexibility in the handling of special industrial wastes were features which were viewed as major attractions for expansion and diversification of the industrial base. Indirectly, the success of the WMS would prove the value of cooperative action in an area noted for its factionalism, providing the basis for further cooperative action in regional development programs. Because the project was conceived and designed as part of an overall development program, it must be judged on the basis of its effect upon the improvement of general community well-being, as well as the immediate impacts.

Study Purpose

The general purpose of the socio-economic component of the study was to measure the impacts of the WMS, both quantified and perceived, in terms of water quality and the water-related environment, economic development and social well-being; to evaluate these impacts in terms of community goals; and to assess national implications and significance of the Muskegon County experience.

As originally conceived, the Muskegon project was expected to produce several major direct impacts: elimination of direct discharges of wastes to waterways, resulting in improvements to water quality and appearance; conversion of fallow land to a valuable agricultural resource; economic growth resulting from increased agricultural production, the initiation of recycling-reclamation and special wastes handling at the wastewater site; increased opportunities for industrial growth based on the unique capabilities of handling industrial wastes; enhancement of recreation tourism opportunities; and the expansion of service commercial facilities brought about by the improvements in water quality and the above-described economic growth.

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*Done by Keifer & Associates, consulting engineers, Chicago, Ill., formerly Bauer Engineering, Inc.

In addition the project was expected to indirectly influence general areas of community change such as the evolution of community goals, community services, general economic conditions, community image, demographic structure, and land use patterns.

Negative impacts were also considered: concerns about public health issues; potential effects of aerosol dispersal of spray irrigation and the capability of the system to adequately control pathogens. Nearby residents expressed concern over odor problems and the possibility of reduced property values. The question of overall cost-effectiveness of such a large-scale land irrigation system was raised.

Many of these impacts are not generally associated with the conventional, single-purpose wastewater treatment systems and it is important to document these impacts in order that this new role for wastewater management can be more fully understood. The importance of doing so is particularly relevant in light of strong indications that the total environmental management of wastewater (and other waste products) is an important factor in restoring and maintaining the nation's environmental quality.

Scope of Study

The time span of the Socio-Economic Study is five years and covers the period from initial construction (1972) through system completion (1972-1973), and several years of system operation (to late 1977). Consequently, change and impact will be measured during the later stages of the system. The geographical scope of the study of impact is Muskegon County which is coterminous with the Muskegon-Muskegon Heights Standard Metropolitan Statistical Area.

The study was originally based on five general components:

Analysis of Socio-Economic Changes and Impact as Shown by Quantitative Indicators –

Using quantitative statistical indicators in such areas as employment, economic development, income and housing, changes in overall socio-economic conditions will be evaluated with emphasis given to the identification of those components of change which are direct or indirect impacts of the Wastewater Management System. The direct or indirect impacts of the wastewater system will be identified and described through a predictive model developed at the outset of the study. Supplemental assessments will be made by monitoring major development decisions and ascertaining (through interviewing those responsible for the decisions) the degree to which these decisions were influenced by the WMS.

Assessment of Water Quality and Related Environmental Changes and Impact –

The environmental changes and impacts (land value, growth and development of the land-water interface and other high-impact areas) will also be analyzed and will complement data concerning economic growth and social well being.

Analysis of Perceived Socio-Economic and Environmental Changes and Impact –

Using perception measuring techniques and other qualitative analysis techniques, socio-economic and environmental impacts will be measured as perceived by a representative sample or subsamples of the study area population. These perceived impacts will be compared to those identified above to determine the degree of consistency, or discrepancy between impacts which are perceived and those which have been determined quantitatively.

Determination of Community Goal Structure and Evaluation of Impacts in Terms of this Goal Structure –

To give change and impact a meaning other than mere magnitude, it is necessary to relate change and impact to an achievement framework; namely, community goals. Impacts as determined in the above will be evaluated in terms of the degree to which they achieve community goals.

Assessment of National Significance –

Study results will be evaluated in terms of the applicability of a similar multi-purpose environmental management system elsewhere in the nation. Emphasis will be placed on the comparative costs with alternative treatment systems; the significance of the income-earning potential and resource recovery and reuse possibilities; and the value of such comprehensive environmental improvement projects as a catalyst for community development.

Study Objectives

A set of study objectives was formulated based on specific interest areas. Each interest area ties together a set of related questions and problems which need to be resolved in order to evaluate the Muskegon experience. The six study objectives are:

1. Changes in water quality
2. The effectiveness of the project as a development catalyst
3. Effects of the WMS site
4. The economics of land treatment
5. Problems of implementation
6. The national significance of the project and the Muskegon planning experience

Changes in Water Quality –

Water quality improvement is the basis for evaluating the ultimate success or failure of the project, making the monitoring of change in water quality a primary study objective. Specifically, the quality of the WMS effluent must be determined together with the changes in quality of the surface waters which were former recipients of sewage effluent; Mona Lake, Muskegon Lake and the Muskegon River. This information is being accumulated and gathered primarily in other portions of the overall study but must be summarized and evaluated in terms of the other objectives. The final treated effluent must also be compared, in terms of pollutant removal efficiency, with conventional secondary treatment and with other advanced waste treatment techniques.

Effectiveness as a Development Catalyst –

Three problems are of particular interest. First, what is the extent of development directly related to the project, e.g. those developments which utilize the WMS's capability to treat wastes. Second, what is the extent of development indirectly related to the WMS, e.g. recreational development based on improved water quality in local water bodies. Third, what types of synergistic uses of the WMS will develop, e.g. agricultural programs, agricultural industries related to crops produced, and an industrial park at the site for special industries.

Effects of the Wastewater Site –

One of the major initial objections to the WMS was the fear of social disruption in the area of the project. A major effort will be devoted to an investigation of hardships caused by individuals forced to relocate. Other issues associated with the site include: the impact of odor problems on surrounding areas, potential public health problems caused by aerosol dispersion, the general effect of the site on values of adjacent properties, ecological changes in the vicinity of the site (particularly impact on wildlife), and the effect on groundwater and surface water resources.

Economics of Land Treatment –

An important issue in the development of a land treatment system are the changes in the costs of treatment for the local community. In addition to evaluating such features as capital costs, operation and maintenance costs, and the return on increased agricultural productivity, the overall cost-effectiveness of the systems needs to be evaluated. Both absolute costs and cost-effectiveness need to be compared to conventional treatment systems and to other technology systems for advanced waste treatment, from both local and national economic perspectives. A final consideration is the perceived benefit of improved water quality versus increased costs, i.e., does the local community perceive the investment for the system as justifiable in light of its perceived achievements?

Problems of Implementation –

The implementation problems include: ramifications of relocation of residents and of site acquisition, financial problems associated with the funding of a very large-scale innovative technology system, and the difficulties of a public service operation based on multi-community cooperation and participation.

National Significance Aspects –

A number of performance aspects of the Muskegon project receive national attention and have national implications with respect to policies and programs for water quality and resource management. These include the following:

1 – Cost of wastewater treatment using Muskegon-type land treatment system compared to alternative AWT technology systems equal in treatment performance

2 – Cost of land treatment compared to cost of current level of conventional waste treatment technology employed to meet 1977 Great Lakes water quality standards

3 – Significance of income earning potential of the agricultural productivity component of land treatment systems

4 – Significance of resources usage, recovery, and reuse as a land treatment system output encompassing:
  a) energy usage compared to requirements of other treatment technologies
  b) wastewater fertilizer recovery by agricultural components
  c) crop productivity value of water reuse for irrigation purposes

5 – Impact of land treatment on soil productivity, site land values for alternative future uses, and land uses and values in areas adjacent to the site

6 – Impact of wastewater treatment costs on the local economy as reflected by the annual wastewater treatment and collection costs as a percentage of total annual local investments in community services

7 – Local citizen reaction to cost-benefit of improved water quality in comparison to other community investment priorities

8 – Role of Muskegon planning and political decision-making process as a model for national application

9 – The applicability nationally of the Muskegon-type wastewater management system addressing factors such as:
  a) site land cost effects
  b) site availability
  c) distance of transmission
  d) site characteristics
  e) climatological factors
  f) agricultural program choices
  g) scale of operations
  h) community goals and political considerations

10 – The opportunity for using environmental management as a catalyst for community economic development and improvement in its social well-being

A WORKING METHODOLOGY

The purpose of the working methodology is to provide a means of identifying the relevant information needed to most efficiently realize the study objectives. Schematically, the working methodology can be visualized as a process composed of five interrelated components, including a model of the socio-economic environmental system, a set of predicted impacts, data collection, a procedure for determining impact from change associated with influences other than the WMS, and a collection of analytic tools to be used in structuring the collection of data and the determination of impact. See Figure 87.

The model represents the primary theoretical framework for the methodology, hypothesizing a series of relationships between an environmental improvement and the appropriate sub-sections of the urban system. In this case, these relationships were adapted to fit the specific situation in Muskegon. These hypothetical relationships were derived largely from the original planning program for the project. The model provides the direction for the development of predicted impacts.

For each area of potential impact outlined in the model, a group of detailed impacts are predicted. These impacts provide the framework and scope required for the data gathering systems. In addition, the predicted impacts provide a basis against which observed socio-economic changes can be compared. The gathering, processing and analysis of data are aided by the use of several analytic tools: community indicators, control and baseline studies, a decision-monitoring system, a perception study, and a relocatee study.

The final step is impact determination. Impact determination draws upon all of the other four components. The predicted impacts provide direction and a hypothesis to test; the analytic tools provide convenient methods for collecting and organizing the data; collected data define the various measured and observed socio-economic changes; and the model outlines relationships between the various segments of the Muskegon socio-economic environmental system and aids in the determination of the degree of impact attributable to the wastewater system. Changes unrelated to the WMS also can be identified.

To aid in defining the scope of the working methodology, two of the components, the model and the analytical tools, are described below in greater detail.

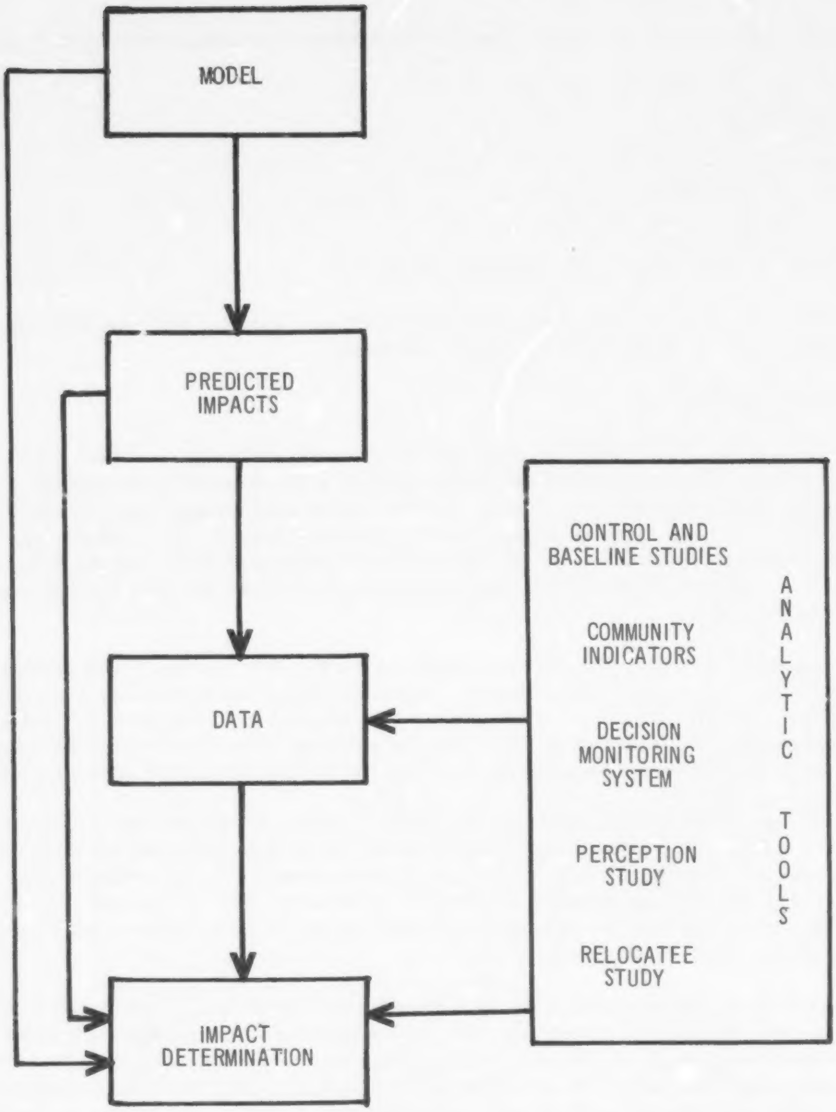

Figure 87. Socio-economic impact study methodology

The Model

An empirical model is the first component of the working methodology of the study. The scheme of the model is diagrammed in Figure 88. Beginning with the WMS in Muskegon, it describes a set of characteristics which identify the system. Each of these characteristics had the potential to cause change in a variety of categories of urban activity; these are identified and collectively called impact categories. Twenty-one have been identified. Finally, the model identifies six categories of community change which measure the total project impact as an investment to achieve improvement of overall community well-being. Collectively, system characteristics, impact categories, and community change categories are linked by a complex set of relationships which represent potential impacts. These linkages between the various categories and characteristics are illustrated in Figure 89.

Analytic Tools for Establishing Community Change

Five techniques were developed for measuring or describing community change within the study area: community indicators, control and baseline studies, a decision monitoring system, a relocatee study and a perception study.

Community Indicators –

These are a list of statistical indicators that characterize the various categories of impact and community change. These relevant statistics, collected for regular time periods, provide a quantifiable means of describing change in the study area. Most of the community indicators selected are published data, applicable to other communities and to the nation. Statistics collected from Muskegon can, therefore, be compared with similar statistics collected for other areas.

Control and Baseline Studies –

Control data are community indicators collected from other areas in addition to Muskegon County. They provide the basis for comparison and the means for distinguishing changes unique to Muskegon County from local, regional, or national changes and trends. Several different types of control areas are used. All of the community indicators gathered for Muskegon that it is feasible to collect in other areas are also obtained for neighboring Oceana and Ottawa Counties. These distinguish regional trends. Statistics from the State of Michigan are used to identify changes occuring throughout the State. In certain areas, comparison with national statistics will isolate changes attributable to national patterns and trends. For certain indicators, statistics from special control areas are also collected. The Grand Rapids and other industrial SMSAs (Standard Metropolitan Statistical Area) in Michigan are used to identify changes as a result of industrial trends on the SMSA level. Two Lake Michigan Shoreline counties that are economically oriented toward the recreation industry are used for distinguishing regional recreation trends.

Baseline data are used to forecast various community indicators in Muskegon on the basis of historical data and projections for conditions preceding the conceptualization and implementation of the wastewater project. Community indicators for Muskegon between 1968 and 1977 can then be compared against forecasts developed from baseline data. Wherever possible, forecasts made prior to the inception of the project are used. Baseline data enables the monitoring nor only rate of change but also of the changes in anticipated rate of change.

Decision Monitoring System –

The monitoring of specified community decisions in the Muskegon study area provides an important information source necessary for the determination of impact. This accumulation of inform-

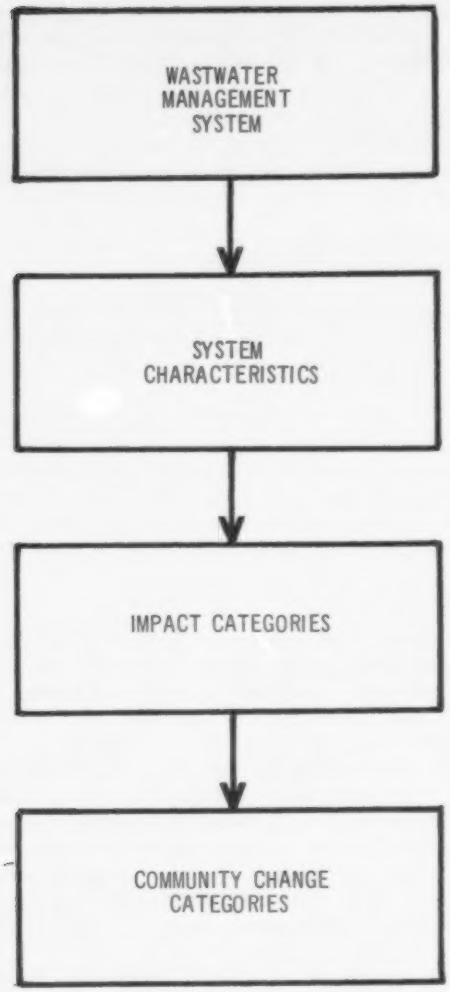

Figure 88. Basic community impact model

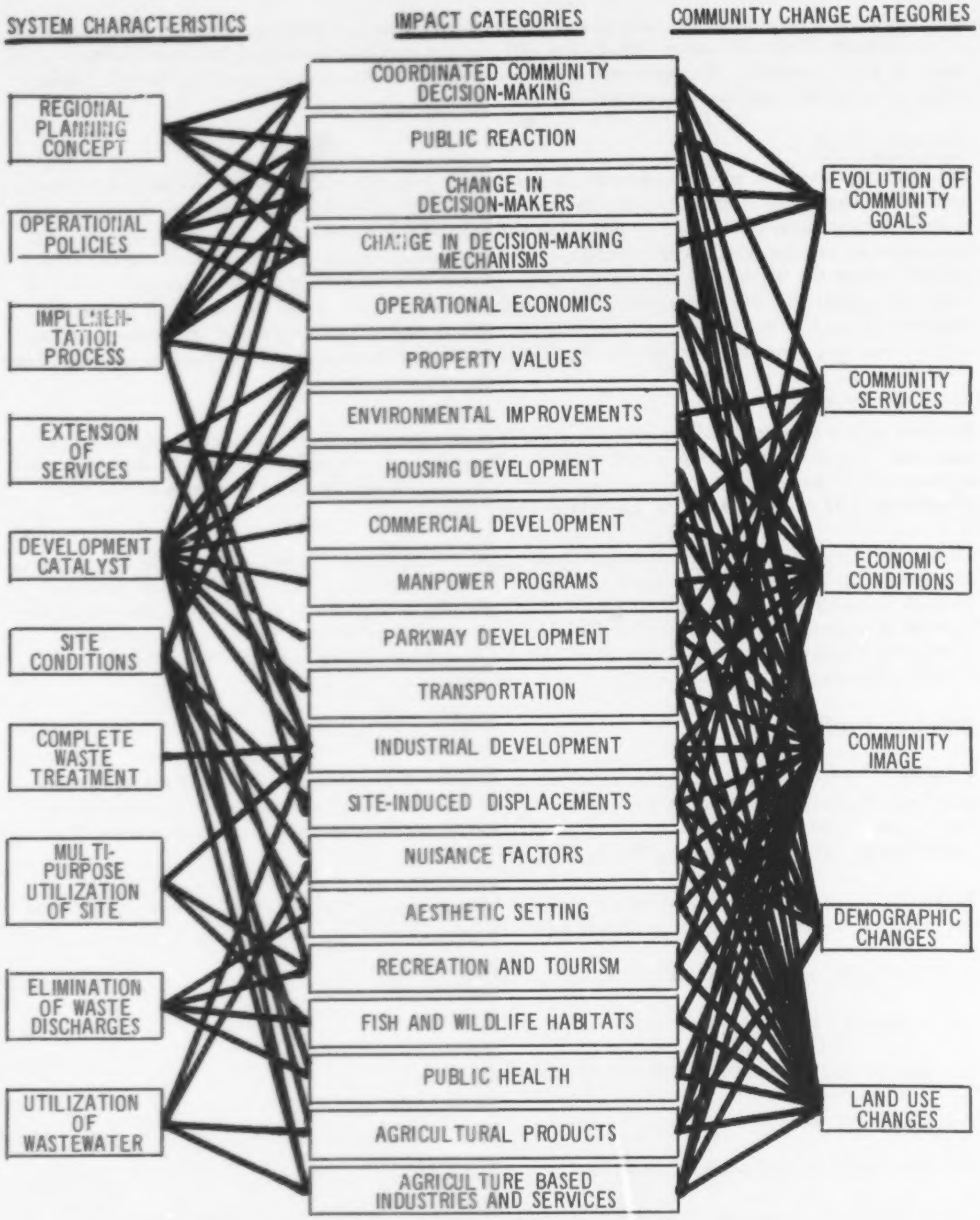

Figure 89. Detailed model linking impact categories with system characteristics and community changes

ation provides a monitor of the progress of planned programs and projects, as well as of major public and private decisions which effect economic, social and developmental policies and programs in the community. The monitoring system consists of two parts: on-going decision monitoring and detailed decision investigations.

Perception Study –

This subtask involves an evaluation of the community perception of project impacts and an examination of changes in community attitudes relevant to WMS-related issues. Special emphasis is placed on community perception of the value and role of the project, the changes in the physical environment, and the changes in overall resident community image. In addition, changes in attitudes toward the importance of environmental quality and community development are examined. Changes in attitudes over the course of the study period are also to be examined. A survey instrument is used in two ways: as a general perception and attitude survey of the region, and as a user's survey, stressing perception of environmental quality and use of environmental amenities.

Relocation Study –

Because of the magnitude of the project, a significant number of former residents was forced to relocate. The relocation study evaluates the relative success or failure of the relocation process in terms of the problems of the relocatees. Also, the effect of relocation programs on the implementation of projects such as the WMS is investigated.

Three main lines of inquiry are pursued in the study. Initially, an information profile emphasizing demographic and economic data is developed for each respondent. These profiles are gathered for both existing situations and pre-WMS conditions. Second, personal reactions to the entire process of relocation are investigated and include the respondent's satisfaction with relocation, values regarding the need and fairness of relocation and subjective opinions regarding their relocation experiences.

SPECIAL STUDIES

A factor of interest in this study is the evaluation of the national applicability of the Muskegon-type land treatment system as a technologic choice for waste treatment for other communities of the country. The principal factors of national significance that relate to this system were discussed previously in the section "Study Objectives."

Technologic aspects of the Muskegon project that are given special attention in terms of national and regional waste management implications include:

1 – The capital and operating cost per unit of volume treated

2 – Operating and maintenance experiences

3 – Agricultural income and productivity potentials

4 – Treatment performance

5 – Environmental and political impacts

6 – Cost-benefit relationships of waste treatment investment as perceived by residents

To adequately assess the level of technical performance of the Muskegon system with respect to the above factors of interest, a comparison is made with alternative relevant waste treatment technology choices. Two types of technology comparisons are made:

1 – A comparison of the cost-effectiveness of the Muskegon system with other AWT systems presently employed to achieve equivalent treatment performance

2 – A comparison of the cost-effectiveness of the Muskegon system with conventional technology presently being employed to meet current Great Lakes water quality standards

Capital, operating, and performance data are available for a number of operational AWT technology systems and other conventional technology systems which were designed and completed to meet Lake Michigan discharge standards at approximately the same point in time as the construction of the Muskegon system.

As an extension of the components of the study dealing with normative evaluation of Muskegon changes, a parallel evaluation is made of water quality improvements and socio-economic changes in a selected comparable community in which a conventional wastewater treatment facility was installed to meet current Lake Michigan discharge standards. This community is selected on a basis of characteristics similar to those of the Muskegon area.

INITIAL FINDINGS

The socio-economic analysis was organized so that the bulk of the analytic work would be addressed in the last year of the study. However, on a broad scale, certain generalizations can be tentatively made regarding initial results of the Muskegon project.

The start of the study (January 1973) corresponds to a midpoint in the construction of the system. Initial findings are discussed in the context of the three principal investigative objectives of the study – Environmental, Social, and Economic Impacts.

Environmental Impacts

To date, four general environmental impacts have emerged; a general improvement in water quality in Muskegon County, the development and resolution of odor problems at the site, increased wildlife populations at the site, and increased aquatic life in Muskegon Lake.

Improvement in Water Quality –

A marked improvement in water quality became evident in Muskegon Lake, a result of the cessation of direct discharge of municipal and industrial wastes into the lake. The most evident changes in quality were visual (clarity, color, and aesthetic appearance). Substantial improvements in basic aquatic productivity in Muskegon Lake have not been observed to date.

Treatment Site Problems –

During the early periods of operation, periodic odor problems existed at the site due to problem wastes from industrial users. Public reaction to the odor was both negative and vigorous, including petitions of protest signed by 600 local residents. A lawsuit was filed by a mobile home park adjacent to the site based on a complaint that the odors had induced many residents to move elsewhere. An odor evaluation study was undertaken in conjunction with a cooperative action program with the problem industries. Corrective action programs by local industries, together with operating adjustments in the aerated treatment cells by the county, greatly reduced the incidence and intensity of odor. The public issue aspects were largely eliminated.

Increased Wildlife –

The treatment site is an ad hoc wildlife preserve for both waterfowl and terrestrial wildlife. Recent studies indicate that the lagoons and cornfields combined make the lagoons one of the major bird sanctuaries for geese and duck in the nation. This conclusion was based upon the very broad range of species observed during waterfowl counts. On lands adjacent to the site, hunting rights were leased. Other wildlife increased on the site as well, due in large part to the abundant food supply and habitat provided by the farmed areas and the adjacent wooded areas. In particular, the local deer herd benefitted from the farmlands as winter feeding grounds. The rabbit population also increased, and the county recently allowed limited winter rabbit hunting on the site.

Increased Aquatic Life in Muskegon Lake –

Improvement of water quality in Muskegon Lake made possible more extensive fish stocking programs. According to Michigan Department of Natural Resources statistics, the annual number of fish stocked in Muskegon Lake grew during the period, 1971 to 1973, from 217,300 to 566,744. Improved water quality also made it possible for the planting of more sensitive species, such as walleyes. The DNR is opening a walleye fishery in the Muskegon Game Area as a step in restoring the walleye runs in the Muskegon River.

Improved aquatic life also affected the amount of fishing activity. Annual non-resident licenses increased 60 percent between 1967 and 1973, and three-day non-resident licenses increased 49 percent between 1972 and 1973.

Social Impacts

Social impacts due to the wastewater project which have become apparent include an increased public consciousness of the lakefront, a public awareness of the value of the WMS and land treatment, and a well defined public reaction to various stages in the development and operation of the system.

Lakefront Consciousness –

The general improvement of water quality in Muskegon Lake resulted in an increased awareness on the part of the community of the value of Muskegon Lake as a community amenity and of the importance of water quality in preserving that amenity. Several examples typify this increased consciousness of the Muskegon lakefront.

In conjunction with the undertaking of the wastewater project, the City of Muskegon and private interests began to redevelop portions of the Muskegon Lake waterfront as a focal point for downtown redevelopment and for general community revitalization. Acquisition of the lakefront site of a former large foundry by the city facilitated the linking of the downtown renewal project to Muskegon Lake, thereby creating opportunities for the enhancement of the attractiveness of the development. The future development of this site is currently under study.

The Muskegon Sportfishing Association was established to encourage tourism through advertising, fishing competitions and other promotions, and cooperative programs with the Michigan DNR. These activities helped to create a demand for increased recreational facilities that will eventually provide greater access to the lake and its shoreline. This demand has resulted in plans for expanding boat launching facilities and the possible developments of beach and camping areas. Several plans for developing and expanding private marinas also emerged.

Public consciousness of the future role of Muskegon Lake as an environmental and economic resource was revealed in the response to the proposed location of a mini-steel mill on the lakefront. Opposition to the steel mill rapidly formed, spearheaded by an environmental action group concerned about the lake and future patterns of shoreline use. Much of the political, industrial and labor interests in the community favored the development of the mill. This was due to the attractiveness of the large number of jobs that would have been created to offset the depressed employment of the county.

The mill controversy led to the requirement that an environmental impact statement be prepared as a condition of obtaining a fill permit from the Corps of Engineers. This delay, together with changes in marketing and product manufacturing plans by the mill along with cost shifts in scrap and power, led to a decision to locate the mill elsewhere.

Community Consciousness of the WMS and Land Treatment –

Among community decision-makers, the wastewater project is recognized as an important resource in the improvement of Muskegon County. Both public and private programs for attracting industrial development stress the capabilities of the treatment system. Public debates regarding the direction and scope of community development almost always make some reference to the role or potential role of the project.

On the other hand, a survey conducted by Muskegon Community College during the spring of 1975 revealed that over 90 percent of the Muskegon County population knew nothing or very little about the WMS. The survey indicated that 48 percent of the sample were completely unaware of it, and an additional 47 percent were familiar with the system but did not understand why it was built. The results of this survey subsequently served as an impetus for a public awareness campaign to make the general populace more familiar with the system and its purposes.

Public Reaction –

The project has been the center of much controversy during its history. Because of its large scope and the size of the public investment and its innovative nature, conflict with vested interest groups was to some extent inevitable.

During the project planning stages, considerable debate arose because of the radical departure of system technology from conventional approaches to wastewater management. The transfer of institutional responsibility to the county from the individual local units of government also became a public issue. The concept of a regional agency was a sensitive issue in the Muskegon area which has a long history of inter-community conflict and factionalism.

During the construction and initial operating period, public reaction to the project shifted to other areas. Increases in construction costs and difficulties with local short-term financing became political issues. Technical difficulties with start-up along with the financing demands necessary for start-up incurred additional political reaction, especially in light of existing county financial difficulties. Conflicts developed between Muskegon County and the private contractor initially hired to operate the system. Conflicts also developed with municipalities over user rate increases which were necessary to recover funding advances to the project by the county.

However, following takeover of the project management by Muskegon County, negative public reaction largely subsided. Reductions in operating costs, the resolution of start-up difficulties, and the realization of substantial revenues from agricultural activities moved the project into a new phase of operational credibility and fiscal solvency.

Economic Impacts

A discussion of the economic impacts of the wastewater system ranges over a number of subjects including: agricultural success of the project, fiscal impacts of project finances on county and local budgets, industrial development, manpower development and unemployment conditions, and synergistic use of the treatment site.

Agricultural Success of the WMS –

During 1975 most operating problems were solved, and the agricultural program performed as expected. Crop yields were favorable. A net profit from the sale of grain helped eliminate financial deficits incurred during the early years of operation.

The total revenue from farming operations grew from $367,566 in 1974, the first year of farming operations, to $715,000 in 1975. In 1975, farming income offset 39 percent of the $1,822,000 of system operating costs.

Fiscal Impacts –

The annual debt service on the project is approximately $1,300,000 per year for $16,000,000 in local bonding. Of the total debt service, 60 percent will be prorated among the local units on a proportional basis which relates service area acreage to total acreage; and 40 percent will be prorated among the local units on the basis of wastewater contributed. The total annual net operating and maintenance costs for 1975 are approximately $900,000, compared to a net operating cost of $1,466,526 in 1974. Net operating cost totals include revenue credits for agricultural crops, R & D refunds, and special services provided to local industries and communities.

The total 1975 capital and O & M cost of $2,200,000 is equivalent to $15.71 for each of the 140,000 county residents served by the system. However, since approximately 65 percent of the present flow is contributed by industrial sources, the actual annual cost burden on local residents averages about $5.50 per capita, or $22.00 for a typical family of four. Actual cost distribution factors may vary from this in individual communities depending upon the methods used to recover the costs paid by the user-municipalities. On a unit volume basis, the total annual cost of treatment by the WMS is approximately $223.00 per million gallons. The operation and maintenance portion amounts to $92.00 per million gallons. These unit volume costs and O & M costs are substantially less than the typical cost of conventional wastewater treatment facilities installed in western Michigan to meet current discharge standards.

For those communities which were largely served by the sewage treatment plants that existed prior to the WMS, the increased cost of waste treatment has been modest. However, for those communities and industries receiving waste treatment services for the first time with the WMS, the cost impact has been significant. Virtually all of the industrial sources were under orders by the Michigan DNR to provide adequate wastewater treatment prior to the conception of the Muskegon project. All of the municipal systems were also under orders to upgrade waste treatment facilities. Recovery of access rights payment costs in those communities where the construction of sewage collection systems were delayed by the lack of federal and state funding has been a special political and economic burden.

Industrial Development –

Several important industrial developments have occurred in Muskegon County for which the WMS had been an important decision factor. A large paper mill underwent a major expansion of its operations after the WMS proved to have the capacity for treating paper mill wastes. Without a treatment system of this capability, the paper mill would have been forced to either invest heavily in its own waste facilities or abandon its operation in Muskegon. It is also likely that the wastewater project prevented other industries with serious waste treatment problems, including a chemical plant and a tannery, from closing down.

After completion of the project, a number of chemical companies announced plans for the location of new plants or the expansion of existing facilities. In all cases, the WMS was cited as an important reason for locating in Muskegon County.

The promotion of industrial development was undertaken by a new organization the Muskegon Area Industrial Expansion Commission (INDEX). One of the focal points of its program is the wastewater treatment system and its potential for accommodating industries with waste treatment problems.

Industrial development was also encouraged by the creation of six industrial parks throughout the county. Four of these parks are presently connected – or will be connected – to the wastewater system.

Manpower and Employment –

The effects of the project on regional employment levels is currently difficult to assess. Some industries would have closed; the fact that they remain viable represents jobs directly attributable to the project. Otherwise, the general national economic recession has so affected Muskegon County as to effectively mask small economic gains.

Manpower programs associated with the project are progressing slowly. The Muskegon Community College only recently applied for federal funds to train students for work at wastewater treatment facilities.

Synergistic Use of the WMS Site –

Planned synergistic uses of the site developed slowly. With the increased population of migratory waterfowl and small mammals, there is the possibility of controlled public hunting.[15]

The development of the proposed on-site industrial park for industries requiring proximity to the treatment facility or for those utilizing the storage lagoons for cooling purposes did not progress beyond the planning stage. Further planning implementation of the industrial park depends upon the commitment of specific industries to the site.

In conjunction with the development of the WMS, an unused portion of the site was set aside to be developed as a regional sanitary landfill site. Although this area was developed during 1973 and operated as a sanitary landfill, the operation became unfeasible financially and ended during the summer of 1975. The landfill closed primarily because of a lack of volume of refuse. As the landfill was being planned, many communities provided letters of intent to use the regional landfill. In addition, new health department regulations were expected to close most local extant landfills. But the other landfills remained in business, and the majority of communities declined use of the regional landfill site. The two communities which did use the site could not provide enough refuse to justify continued operation.

SECTION 13

ECONOMICS

The goal of all wastewater treatment methods is to improve water quality. It is generally true that both construction costs and operational costs of a treatment facility go up in direct proportion to the improved quality of discharge water. So if a conventional treatment plant is expensive, a land treatment facility may be even more expensive.

The Muskegon system was designed to serve many municipalities, but in order to reduce costs of transmission from the northern cities of Whitehall and Montague, a satellite facility was constructed to serve that area. Construction on both sites proceeded simultaneously with single contracts issued for component jobs at either site.

Through December 31, 1975, the total construction costs, audited by Alexander Grant and Company, for both treatment systems was found to be $42,651,949.20. Other costs, not capitalized, included such period items as administration expenses, losses on sale of properties, interest on notes issued to contractors, and payment to other municipalities. See Table 99.

This breakdown of total costs for the Muskegon subsystem is here presented in accordance with the format for capital costs as specified in the EPA Technical Report 430/9-75-003, "Costs of Wastewater Treatment by Land Application," June, 1975.

Certain costs should be segregated when making comparisons between the EPA publication estimated costs and WMS costs. These special costs, not included in the EPA guidelines, are itemized below and are here included for the benefit of engineering firms or planners who might be interested in these cost categories.

Clay lining of storage lagoons	$ 804,098
Concrete pipe extending into storage lagoons	100,000
Mixers in aeration cells	270,000
Cement in aeration cells in lieu of riprap	621,450
Asphalt roadway around aeration cells	314,810
Utility relocation	295,468
Relocation of residents	1,165,710
Other miscellaneous	64,611
Total special costs	$ 3,636,147

Table 99. MUSKEGON COUNTY WASTEWATER MANAGEMENT SYSTEM COSTS DECEMBER 31, 1975[a]

Line item	Cost
Land	$ 6,648,327.97
Land improvement	1,325,262.11
Buildings	1,026,005.52
Lagoons (storage and aeration cells)	9,461,611.39
Fence	130,556.08
Road improvements	129,474.47
Pipes, structures, force mains, sewers, ditches, and miscellaneous	9,950,893.80
Mechanical and electrical systems	3,841,683.61
Machinery and equipment	
Farm machinery and equipment	452,543.34
Treatment equipment	151,637.01
Laboratory equipment	109,210.40
Maintenance equipment	110,609.71
Vehicles	59,459.59
Office equipment and furniture	13,304.78
Irrigation equipment (center pivot rigs)	1,359,012.30
Irrigation distribution	4,480,293.50
Capitalized engineering	2,303,601.43
Capitalized interest	880,947.67
Deferred loan issue costs	217,514.52
Subtotal	$ 42,651,949.20
Other costs (not capitalized)	834,644.96
Total	$ 43,486,594.16
Assets added by purchase after construction was complete (net)[b]	203,179.63
Total construction and equipment	$ 43,486,414.53

[a] Cost includes Muskegon and Whitehall systems

[b] Earth moving, heavy equipment, corn storage facilities and related items

Of these excepted special costs, two require further clarification. In the EPA guidelines, provisions have been made for service roads; however, the asphalt paving material has been removed for this comparison since it is not a necessary component of a service road. The clay lining has also been removed since the guidelines only make provision for lining of the entire inside area of the reservoir. The storage lagoons of the Muskegon system are only partially lined and therefore, for the purpose of this comparison, the linings have been removed.

CONSTRUCTION COSTS

The derivations of the cost items in Table 100 were in compliance with the specifications of the EPA cost estimation guidelines and do not include those special costs listed on Page 252. Specific references to EPA Technical Report 430/9-75-003 are provided per each item below.

Preapplication Treatment

Figures 16, 17; pp 69, 71; on the basis of 160 TCMD. Capital cost: included excavation, embankment, and seeding of lagoons, service roads (less asphalt material), fencing, riprap embankment protection, hydraulic controls, aerating and electrical equipment, chlorination with flash-mixing and contact basin, chlorine storage, flow meters.

Transmission Pipe Line

Figures 20, 21; pp 77, 70; on the basis of 1.9m pipe and 75 meter/head. Capital costs: include pipe and fittings, excavation, bedding, backfill, testing, cleanup, enclosed wetwalls, pumping equipment plus standby, pipe, valves, controls, electrical work.

Storage

Figure 23, p 83; on the basis of 19.3 million cubic meters. Capital costs: include dikes and embankment protection but does not include the cost of any lining.

Field Preparation

Figure 24, p 85; on the basis of 2,860 hectares brush and trees. Capital costs: bulldozer clearing.

Distribution

Figures 28, 33; pp 93, 103; on the basis of 2,860 hectares, 160 TCMD. Capital costs include: center-pivot rigs, electric drive, water screens, pumping equipment plus standby, pipe, valves, controls, electrical work.

Recovery

Figures 34, 38; pp 105, 113; on the basis of 2,860 hectares, 160 TCMD. Capital costs include: buried drain pipes, interception ditch, discharge controls, wells, vertical turbine pumps, well sheeters, controls, electrical work.

Additional Costs

Facilities –

Figure 39, p 115; on the basis of 160 TCMD. Capital costs include: administration and laboratory building, laboratory equipment, shop, garage.

Table 100. MUSKEGON COUNTY WASTEWATER MANAGEMENT SYSTEM ANALYSIS OF CAPITAL COSTS IN CONSTRUCTION – MUSKEGON SUBSYSTEM

Line item	WMS actual cost		Average EPA estimated costs for 1974-1975	
	Total cost	Annual amortization[a]	Total cost	Annual amortization[a]
Preapplication treatment	$ 631,714.25		$ 1,140,000.00	
Transmission	6,822,335.29		7,324,800.00	
Storage	4,404,072.38		5,000,000.00	
Field preparation	1,915,027.14		2,500,000.00	
Distribution	4,092,670.26		5,600,000.00	
Recovery	3,732,071.25		1,900,000.00	
Additional costs	1,355,869.51		1,665,000.00	
Subtotal	$ 22,953,760.08		$ 25,129,800.00	
Service and interest factor	3,839,036.00		6,282,450.00	
Subtotal	$ 26,792,796.08	$ 2,529,239.95	$ 31,412,250.00	$ 2,965,316.00
Land at	5,449,921.96	514,472.63	10,800,000.00	1,019,520.00
Total	$ 32,242,718.04	$ 3,043,712.58	$ 42,212,250.00	$ 3,984,836.00

[a] Amortization: I = 7 percent, M = 20 years, CRF = 0.0944, PWF = 0.2584

Table 101. ANALYSIS OF OPERATIONS AND MAINTENANCE COSTS, 1975[a]

Line items	WMS actual costs				EPA guidelines
	Labor	Electric power	Materials and services	Total	Operations and maintenance costs
Preapplication treatment					
Aerated lagoon number 1	$ 1,663.81	$ 91,163.97	$ 1,010.54	$ 93,838.32	$ 94,252.00
Aerated lagoon number 2	556.53	39,574.96	1,183.43	41,314.92	94,252.00
Aerated lagoon number 3	1,212.21	18,765.33	582.62	20,560.16	94,252.00
Chlorination	2,172.63		11,035.28	13,207.91	67,431.00
				$ 168,921.31	$ 350,187.00
Transmission					
Force main					$ 9,488.00
Effluent pumping	$ 97,395.07	$ 161,960.98	$ 48,947.47	$ 308,303.52	329,490.00
				$ 308,303.52	$ 338,978.00
Storage					
Settling, outlets and storage lagoons	$ 5,020.27		$ 8,187.64	$ 13,207.91	$ 161,923.00
				$ 13,207.91	$ 161,923.00
Distribution					
North irrigation pumping station	$ 17,372.72	$ 71,823.48	$ 10,231.47	$ 99,427.67	$ 184.266.00
South irrigation pumping station	9,610.29	31,326.17	8,326.69	49,263.15	184,266.00
Irrigation rigs	94,356.30	9,546.31	147,028.15	250,930.76	549,298.00
				$ 399,621.58	$ 917,830.00
Recovery					
Drainage system	$ 1,402.65	$	$ 731.25	$ 2,133.90	$ 73,507.00
North drainage station	3,133.07	6,754.78	1,341.11	11,228.96	33,343.00
Sullivan drainage station	3,604.35	9,579.09	1,732.96	14,916.40	33,343.00
Laketon drainage station	3,567.28	2,208.08	1,727.18	7,502.54	33,344.00
Drainage wells	1,903.23		2,141.92	4,045.15	
				$ 39,826.95	$ 173,537.00

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[a] Muskegon and Whitehall systems

Table 101 (continued). ANALYSIS OF OPERATION AND MAINTENANCE COSTS, 1975[a]

	WMS actual costs				EPA guidelines
Line items	Labor	Electric power	Materials and services	Total	Operations and maintenance costs
Additional costs					
Administration	$ 59,401.32	$	$ 84,053.63	$ 143,454.95	$
Farm	99,839.66	4,716.83	281,678.57	386,235.06	425,000.00
Laboratory	7,460.47		14,348.81	21,809.28	
Water quality studies	35,830.02		7,237.49	43,067.51	
Treatment performance studies	69,601.37		9,149.17	78,750.54	
Farm management	22,764.15		2,462.80	25,226.95	
Agricultural productivity studies	23,279.32		4,075.34	27,354.66	
Socio-economic studies			10,000.00	10,000.00	
Project administration studies			7,432.01	7,432.01	
Outside laboratory services	4,346.37		865.36	5,211.73	
Operation equipment maintenance	8,614.51		26,336.95	34,951.46	
Administration building	14,437.96	21,348.55	9,423.47	45,209.98	66,543.00
Fences and roadways	4,583.76	1,299.41	5,975.78	11,858.95	56,900.00
Solid waste	2,295.36	9.11	1,455.09	3,759.56	
Monitoring wells					43,306.00
				$ 844,322.64	$ 592,749.00
Benefits					
Sale of crop – Corn			$-699,486.90	$ -699,486.90	$ -575,000.00
– Wheat			- 7,402.88	- 7,402.88	
– Soybeans			- 908.04	- 908.04	
Laboratory services			- 7,687.50	- 7,687.50	
Miscellaneous income			- 5,784.03	- 5,784.03	
Federal grants			-182,669.45	-182,669.45	
				$ -903,938.80	$ -575,000.00
Total operations expense	$ 595,424.68	$ 470,077.05	$-195,236.82	$ 870,264.91	$ 1,960,204.00
Amortization (0.0944 x capital cost)[b]				$ 3,043,712.58	$ 3,984,863.00
Total				$ 3,913,977.49	$ 5,945,067.00
Rate at 102.6 TCMD current flow ($/TCM)				$ 104.51	
Rate at 160 TCMD design flow ($/TCM)					$ 101.80

[a] Muskegon and Whitehall systems

[b] Amortization: I = 7 percent, M = 20 years, CRF = 0.0944, PWF = 0.2584

Wells –

Figure 40, page 117; on the basis of 13 meter well depth. Capital costs include; drilled wells, vertical turbine pump, controls, electrical work.

Service Roads and Fencing –

Figure 41, page 119; on the basis of 2,860 hectares. Capital costs include: gravel service roads, 1.3 meter fence.

Service and Interest Factor –

Calculated as 25 percent of direct cost; including engineering, legal, fiscal, interest during construction, contingencies.

Land –

Computed at $2,500/hectare.

In those cases of EPA charts cited above which do not include flow capacities as high as 160 TCMD, extrapolations were made.

COSTS OF OPERATIONS – MAINTENANCE

Operational costs in 1975 were similar to the EPA published estimates, in spite of the classification as a demonstration project with the special cost-featured outline above. As indicated in Table 101; project costs (total expenses and 20 year amortization) were $104.51/TCM versus the EPA projection of $101.80/TCM.

Average daily flow was 27 MGD (102.6 TCM), well below the design flow of 42 MGD (160 TCMD), but as flow increases, it is expected that the cost per TCM will decline, even though the overall cost will increase slightly.

The Muskegon operations and maintenance costs and EPA publication estimates in Table 95 were developed from the same figure/page as was used to outline the capital cost comparison in Table 94.

Details of costs for 1974 and before were not available when the county assumed management of the system in December, 1974. However, 1974 costs are presented in summary form in Table 102 and compared with 1975.

Table 102. SCHEDULE OF OPERATING COSTS,[a] 1974 AND 1975

Line item	1974 cost	1975 cost
Direct materials & services depreciation	$ 975,408.00	$ 1,205,949.50
Direct labor	398,397.00	462,875.93
Overhead and fringe	116,614.00	111,146.01
Administration	543,412.00	154,277.51
Total	$ 2,033,831.00	$ 1,934,248.95

[a] Including collection and transmission, Whitehall and Muskegon subsystem operating expenses

Table 103 presents a comparison of 1974 and 1975 electrical consumption, KWH, and dollars. Significant reductions in KWH consumption were achieved by improved management. Though costs increased $32,523.35 and electrical KWH consumption declined 22,629,479 KWH, the increase in cost was due to higher fuel adjustment charges.

Table 103. ELECTRICITY CONSUMPTION AND COSTS, 1974 AND 1975[a]

	1974		1975	
Purpose	KWH	Cost, $	KWH	Cost, $
Lift stations	11,095,475	162,178.82	10,780,900	218,472.54
Treatment operations	22,421,492	224,214.92	9,009,300	182,578.64
Irrigation system	9,483,005	94,830.05	5,702,700	112,695.96
Total	42,999,972	481,223.79	25,492,900	513,747.14

[a] Muskegon and Whitehall systems

KWH consumption and dollars were taken from Consumers Power billings, and distribution was calculated for each bill based on meters.

Table 104 presents 1975 labor expenses. 1974 labor expanses were not available because of the change in management.

Table 104. 1975 LABOR EXPENSES[a]

Purpose	Manpower[b]	Direct labor and fringe, $
Operation and maintenance[c]	15	$ 234,119.15
Spray rig maintenance	4	59,623.45
Farm operations	6	65,523.70
Equipment maintenance	3	51,473.94
Laboratory	10	163,281.70
Administration	3	63,882.69
Total	41	$ 637,904.63

[Annual gallonage flow 9,778.15MG (2MCM). Labor rate = $65.24/MG ($17.16/TCM)]

[a] Muskegon and Whitehall systems

[b] Eight part-time, temporary, or seasonal employees with durations of employment from one to four months are not included in the manpower listing. Their wages are included in direct labor and fringe, amounting to approximately 3,800 man hours.

[c] Includes personnel from Whitehall system and collection personnel. For Whitehall approximately 1,400 man hours.

The breakdown of 1975 costs of operation and maintenance of the aeration cells, storage lagoons and irrigation circles is in Table 105. It should be noted that whereas the total maintenance costs for the storage lagoons was only $48,000, or about 25 percent of the cost of the aeration cells, original design did not allow for wastewater treatment by lagoon impoundment per se. Treatment effectiveness was expected from the aeration cells. But through the treatment performance studies it was discovered that lagoon impoundment provides considerably more effective wastewater treatment than aeration, and at considerable savings. (See Figures 52 and 54.) The electrical costs of the aeration cells in 1975 were three times the total maintenance costs of the lagoons and would have been even higher had the policy of aeration cell use not been modified.

In the case of the irrigation circles, 1975 costs of materials and services were remarkably low, less than $17,000 for 57 irrigation machines. The irrigation portion of the system represents the "advanced" (or tertiary) treatment and has a cost rate of about $30/MG (3.8 TCM), which is significantly less than the costs of conventional advanced wastewater treatment systems.

Table 105. COSTS OF OPERATION AND MAINTENANCE OF AERATION CELLS, LAGOONS AND IRRIGATION CIRCLES, 1975[a]

Purpose	Aeration cells	Storage lagoons	Irrigation circles
Salaries and fringes	$ 2,685.34	$ 5,627.11	$ 94,886.44
Public utilities	149,504.26		112,695.96
Direct materials and services	1,347.22	21,927.99	16,909.15
Subtotal	$ 153,536.82	$ 27,555.10	$ 224,491.55
Laboratory	$ 31,987.90	$ 15,993.96	$ 31,987.90
Administration	7,660.26	4,673.77	30,313.76
Total	$ 193,184.98	$ 48,222.83	$ 286,793.21

[a] Muskegon and Whitehall systems

Total User Charge, 1975

To arrive at the 1975 operating rate of $143/MG or $37.78/TCM, all expenses incurred by the system were totaled, and from that sum was subtracted anticipated revenues. This net figure divided by the expected annual gallonage was the cost that users of the system were charged for that component of the user rate. The other items in Table 106 bring the total operational cost to users per million gallons to $170, but this does not include a debt retirement fee of $45/MG or $11.89/TCM.

Table 106. 1975 USER RATE COMPONENTS

Purpose	Fee, $ per MG	Fee, $ per TCM
1975 operating budget	$ 143.00	$ 37.78
Operating deficit of prior years	8.00	2.11
1975 depreciation (machinery and equipment only)	11.50	3.04
Working capital requirements	5.00	1.32
Interest on deficit	2.50	0.66
Total operational cost to user[a]	$ 170.00	$ 44.91

[a] Not including debt retirement fee of $45/MG or $11.89/TCM

The above operating rate of $143/MG is elaborated upon in Table 107, giving figures for the budgeted expenses of labor and fringe, electricity, maintenance and materials, fertilizers and required services.

Table 107. 1975 BUDGETARY RATE

Item	Credits	Debits
Budgeted expense[a]		$ 2,151,318.00
Forecasted income		
Crop revenue[b]	$ 555,000.00	
Contractual services[c]	35,000.00	
EPA grant[d]	155,000.00	
Total	$ 745,000.00	(–745,000.00)
Cost to be recovered		$ 1,406,318.00
[At flow rate of 27MGD (102.6TCMD = $143.00/MG ($37.78/TCMD)]		

[a] Includes labor, fringe, materials, electricity and services but does not include capital outlay

[b] Includes corn, $540,000 and wheat, $15,000

[c] Laboratory analyses fees to industry

[d] 75 percent federal reimbursement for treatment performance water quality, agricultural productivity studies as well as other reimbursable studies

The many startup difficulties of 1973 and 1974, including low yields, installation delays, cable faults, etc., resulted in a deficit. Users agreed to spread payment of this deficit over a 10 year period, allowing that during that period any surplus should be used to reduce the deficit. (At the beginning of 1975, the deficit amounted to $934,463.97, and at the end of the year the deficit was $212,145.50.) In addition, the users agreed to generate funds for working capital to cover depreciation of machinery and equipment and to pay to Muskegon County six percent interest for advancing to WMS capital sufficient to cover the deficit. That equipment and machinery funded by users was projected to last ten years or less.

It should be noted that working capital was accidentally omitted from all design data.

As indicated in Table 108, the "actual operational rate" per million gallons was considerably less than the "budgetary rate:" $106/MG versus $170/MG. This reduction was achieved by revenue from crop yields, saving in electrical expenses and lower material expenses.

Table 108. 1975 ACTUAL OPERATIONAL RATE

Item	Credits	Debits
Actual expense		$ 1,934,212.61
Actual income		
Crop revenue[a]	$ 707,797.82 [b]	
Contractual services	7,687.50	
EPA grant	182,669.45	
Miscellaneous	5,784.03	
Total	$ 903,938.80	(-903,938.80)
Cost to be recovered		$ 1,030,273.81
[At flow rate of 27 MGD (102.6 TCMD) = $104.54/MG[c] ($27.51/TCM)]		

[a] Crop revenues include:

Corn	$699,486.90	(267,269 bu at $2.617/bu)
Wheat	7,402.88	(2,553 bu at $2.90/bu)
Soybeans	908.04	(303 bu at $3.00/bu)

[b] Includes 1975 corn crop sales

[c] Component costs:

Operations expense	$92.44
Depreciation	9.14
Interest on deficit	2.96

SECTION 14

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Appendix A, Table 1. INDIVIDUAL SAMPLE VOLUMES FOR THE ENRESCO IRRIGATION RIG ON CIRCLE 39 COEFFICIENT OF UNIFORMITY TEST AT SPRAYBAR PRESSURE OF 210 gm/cm^2

Sample #[a] $\Sigma V/n$[b, d] $\Sigma CU/n$[c, d]	Row	Sample volume, cm^3 Cup number 1	2	3	4	5	6	7	8	9	10	11	12	13
Span I	X	22	8	12	2	59	15	0	0	0	0	0	0	0
$\Sigma V/n = 17.5$	Y	17	18	17	14	14	0	0	0	0	0	0	0	0
$\Sigma CU/n = 49.7$	Z	6	8	16	10	46	14	0	0	0	0	0	0	0
Span II	X	12	10	13	14	15	22	15	13	17	21	0	0	0
$\Sigma V/n = 16.5$	Y	15	11	2	30	17	14	17	0	22	0	0	0	0
$\Sigma CU/n = 71.5$	Z	11	12	17	19	27	10	15	20	30	22	0	0	0
Span III	X	0	12	5	18	5	27	15	11	15	32	0	0	0
$\Sigma V/n = 16.2$	Y	19	0	11	19	10	20	15	10	20	0	0	0	0
$\Sigma CU/n = 58.1$	Z	35	10	10	20	9	13	9	15	9	44	0	0	0
Span IV	X	8	14	12	8	12	8	13	20	20	25	0	0	0
$\Sigma V/n = 13.6$	Y	10	14	5	14	21	14	15	10	12	0	0	0	0
$\Sigma CU/n = 69.9$	Z	5	18	20	10	18	8	13	12	12	23	0	0	0
Span V	X	35	11	12	13	10	13	26	12	20	9	0	0	0
$\Sigma V/n = 15.2$	Y	16	14	13	12	31	13	11	12	12	0	0	0	0
$\Sigma CU/n = 65.4$	Z	27	13	11	12	25	10	12	8	18	10	0	0	0
Span VI	X	16	16	26	15	15	43	19	11	15	13	0	0	0
$\Sigma V/n = 16.3$	Y	14	15	15	27	14	11	15	13	10	0	0	0	0
$\Sigma CU/n = 73.4$	Z	13	12	24	15	13	19	13	13	0	10	0	0	0
Span VII	X	16	16	21	13	18	27	15	18	17	26	0	0	0
$\Sigma V/n = 18.3$	Y	12	14	19	25	16	15	15	17	15	0	0	0	0
$\Sigma CU/n = 78.3$	Z	14	15	25	11	25	28	22	22	15	19	0	0	0

[a] Each sample consists of 13 cups in each of three rows (X, Y & Z) for a total of $n = 39$

[b] Average volume in cubic centimeters for each cup sample collected

[c] Average coefficient of uniformity for each sample

[d] For the entire Enresco rig ($n = 273$): $\Sigma V/n = 16.2$, $\Sigma CU/n = 67.0$

Appendix A, Table 2. INDIVIDUAL SAMPLE VOLUMES FOR THE LOCKWOOD IRRIGATION RIG ON CIRCLE 40 COEFFICIENT OF UNIFORMITY TEST AT SPRAYBAR PRESSURE OF 700 gm/cm^2

Sample #[a] $\Sigma V/n$[b, d] $\Sigma CU/n$[c, d]	Row	Sample volume, cm^3												
		Cup number												
		01	02	03	04	05	06	07	08	09	10	11	12	13
Span I	X	0	14	37	67	64	35	36	40	29	38	37	47	0
$\Sigma V/n=41.7$	Y	0	21	48	55	39	53	36	45	28	36	39	30	0
$\Sigma CU/n=74.2$	Z	0	27	30	88	67	47	38	41	28	49	39	48	0
Span II	X	54	34	48	35	50	49	39	38	47	50	63	34	36
$\Sigma V/n=48.3$	Y	67	65	67	54	46	48	53	46	44	41	48	53	43
$\Sigma CU/n=85.9$	Z	56	41	52	45	55	58	45	40	44	59	50	41	47
Span III	X	29	42	43	44	48	31	38	40	55	70	38	54	36
$\Sigma V/n=44.1$	Y	45	48	0	50	47	36	55	32	44	45	57	53	25
$\Sigma CU/n=81.4$	Z	45	30	47	49	62	36	34	36	58	62	38	37	38
Span IV	X	24	0	36	57	30	58	40	48	34	78	44	39	34
$\Sigma V/n=40.1$	Y	0	40	0	52	34	32	33	64	40	32	32	32	43
$\Sigma CU/n=75.7$	Z	22	58	30	47	28	51	30	32	30	44	52	29	33
Span V	X	32	0	39	32	25	37	38	44	35	39	35	31	29
$\Sigma V/n=35.9$	Y	38	42	42	41	43	46	32	37	33	36	43	34	28
$\Sigma CU/n=86.3$	Z	24	27	43	32	24	34	39	41	33	43	37	44	33
Span VI	X	29	23	32	34	41	33	34	31	30	27	32	48	0
$\Sigma V/n=37.8$	Y	30	38	0	53	42	44	32	36	44	48	47	56	42
$\Sigma CU/n=81.8$	Z	23	32	39	47	47	38	34	35	45	32	36	48	0
Span VII	X	31	38	41	47	46	33	32	50	38	50	29	38	28
$\Sigma V/n=39.7$	Y	33	32	31	33	33	29	28	39	39	39	34	40	26
$\Sigma CU/n=81.1$	Z	31	57	62	63	47	42	50	47	44	37	48	47	35
Span VIII	X	32	33	46	48	47	43	43	36	57	55	42	41	50
$\Sigma V/n=44.4$	Y	29	43	43	42	44	54	50	48	34	41	47	54	42
$\Sigma CU/n=87.0$	Z	29	37	49	51	39	50	45	39	58	46	47	43	53
Span IX	X	36	40	44	46	40	49	42	50	36	37	60	52	49
$\Sigma V/n=44.8$	Y	33	42	36	57	57	38	40	51	44	42	45	44	47
$\Sigma CU/n=87.6$	Z	47	40	48	47	43	0	48	48	39	29	54	54	47
Span X	X	41	31	37	49	47	44	51	50	0	47	47	44	45
$\Sigma V/n=44.6$	Y	40	40	40	41	40	58	40	47	59	47	47	43	60
$\Sigma CU/n=88.9$	Z	43	33	40	38	50	45	51	45	49	40	48	39	39
Span XI	X	23	40	47	66	0	0	0	0	0	0	0	0	0
$\Sigma V/n=44.9$	Y	30	63	33	60	0	0	0	0	0	0	0	0	0
$\Sigma CU/n=72.0$	Z	64	44	41	28	0	0	0	0	0	0	0	0	0

[a] Each sample consists of 13 cups in each of three rows (X, Y & Z) for a total of n=39

[b] Average volume in cubic centimeters for each cup sample collected

[c] Average coefficient of uniformity for each sample

[d] For the entire Lockwood rig (n=429): $\Sigma V/n=42.39$; $\Sigma CU/n=81.4$

Appendix A, Table 3. MAXIMUM AVERAGE WATER APPLICATION RATE EFFICIENCY TEST FOR THE LOCKWOOD IRRIGATION RIG

Timer setting, percent	Weather				Wind		Solar radiation, g-cal/hr	Rig parameters				CU[b] percent
	Con-dition	Temper-ature, °C	Relative humidity, percent	Precip-itation, cm	Speed, kmph	Direction		Flow rate, m3/hr	Pres-sure, kg/cm2	Application rate, cm/rev		
										Theo-retical[a]	Observed	
100	Cloudy	27	40	0	16	S	1.00	290	1.76	1.09	1.22	84.0
90	Cloudy	26	42	0	16	N	0.90	290	1.76	1.19	1.40	83.8
80	Cloudy	26	44	0	16	SW	0.80	269	1.69	1.24	1.35	82.9
70	Cloudy	26	48	0	16	SW	0.70	269	1.69	1.42	1.55	79.3
60	Cloudy	25	50	0	24	W	0.60	267	1.69	1.68	1.78	87.2
50	Cloudy	25	50	0	24	W	0.50	267	1.69	2.01	2.24	80.7
40	Clear	20	46	0	23	W	1.40	272	1.69	2.54	2.79	87.8
30	Clear	19	50	0	24	W	1.20	274	1.69	3.40	3.63	88.4
20	Clear	19	50	0	24	W	1.00	260	1.69	4.90	4.90	85.5
10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] Corrected for flow varying flow rate
[b] Coefficient of uniformity

Appendix A, Table 4. MAXIMUM AVERAGE WATER APPLICATION RATE EFFICIENCY TEST FOR THE ENRESCO IRRIGATION RIG

Timer setting, percent	Weather								Rig parameters				
	Con-dition	Temper-ature, °C	Relative humidity, percent	Precip-itation, cm	Wind		Solar radiation, g-cal/hr	Flow rate, m3/hr	Pres-sure, kg/cm2	Application rate, cm/rev		CU[b], percent
					Speed, kmph	Direction				Theo-retical[a]	Observed	
100	Cloudy	27	48	0	13	SW	1.10	364	0.21	0.43	0.38	74.0
90	Cloudy	27	41	0	13	SW	1.10	364	0.21	0.48	0.43	74.5
80	Cloudy	28	41	0	16	SW	1.10	364	0.21	0.53	0.48	69.2
70	Clear	27	43	0	16	W	1.00	364	0.21	0.61	0.58	79.8
60	Clear	28	40	0	19	W	1.20	364	0.21	0.71	0.71	79.9
50	Clear	27	44	0	19	W	0.60	364	0.21	0.84	0.73	72.5
40	Clear	26	43	0	24	SW	0.50	364	0.21	1.07	0.89	78.0
30	Cloudy	19	64	0	16	SW	0.40	364	0.21	1.42	1.30	80.3
20	Cloudy	18	80	0	13	SW	0.20	364	0.21	2.11	1.65	79.0
10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] Corrected for flow varying flow rate
[b] Coefficient of uniformity

Appendix A, Table 5. WIND DRIFT AT 60 METERS

	In 15 to 25 kmph wind			In 30 to 45 kmph wind		
(d) Droplet diameter range, μ	(n) Number of droplets	(dn) Number × diameter	Percent of total	(n) Number of droplets	(dn) Number × diameter	Percent of total
1 → 13	2	26	0			
13 → 27	15	405	2	35	945	2
27 → 40	32	1280	6	71	2840	6
40 → 54	49	2646	12	52	2808	6
54 → 67	44	2948	14	61	4087	9
67 → 81	60	4860	23	62	5022	11
81 → 94	23	2162	10	62	5828	12
94 → 108	13	1404	7	43	4644	10
108 → 121	12	1452	7	35	4235	9
121 → 135	8	1080	5	29	3915	8
135 → 148	8	1184	6	18	2664	6
148 → 162	4	648	3	12	1944	4
162 → 175	3	525	2	8	1400	3
175 → 189	2	378	2	3	567	1
189 → 202	0	0	0	4	808	2
202 → 216	1	216	1	1	216	0
216 → 229	0	0	0	2	458	1
229 → 243	0	0	0	4	972	2
243 → 256	0	0	0	0	0	0
256 → 270	0	0	0	2	540	1
270 → 283	0	0	0	2	566	1
283 → 297	0	0	0	1	297	0
297 → 310	0	0	0	1	310	1
310 → 324	0	0	0	3	972	2
324 → 337	0	0	0	0	0	0
337 → 351	0	0	0	0	0	0
351 → 364	0	0	0	0	0	0
364 → 378	0	0	0	1	378	1
378 → 391	0	0	0	0	0	0
391 → 405	0	0	0	2	810	2
Total	$\Sigma n = 276$	$\Sigma dn = 21214$	100	$\Sigma n = 514$	$\Sigma dn = 47226$	100
	$\Sigma dn / \Sigma n$ = Average mean diameter = 77			$\Sigma dn / \Sigma n$ = Average mean diameter = 92		

Appendix B. Operations and Maintenance

This Appendix details the maintenance procedures for three aspects of the WMS operations: the collection system with itemizations for each lift station, the aeration equipment and the irrigation pump stations.

A. Collection System

The system was maintained by eight men who, with a four-man swingshift schedule, manned C – station 24 hours per day, seven days per week, and observed the conditions at six other stations (A, B, D, F, G and J) by means of a remote monitoring system. The remote monitor provides information on the number of pumps in operation, power supply and status of wet wells at each location.

Monday through Friday, the eleven stations were routinely inspected by one operator-mechanic, and two repairmen were dispatched to handle major malfunctions. The Muskegon personnel also spent some time servicing the Whitehall collection subsystem.

Individual maintenance operations for eash lift station were:

Lift Station A (0 TCMD). Because there is no sanitary sewer in this area, this station was not in service in 1975 and required little maintenance.

Lift Station B (1.18 TCMD).
– replacement of wiring on a sequence switch
– replacement of burned out motor on ventilating fan

Lift Station C (97.29 TCMD).
– repainting of bar screen room
– installation of a new driveway
– installation of additional radio components to expand radio communication throughout the C-station complex and with the treatment site
– replacement of the steel cables on the bar screen rakes with stainless steel models
– removal from service of the Badger flowmeter which measured flow in the City of Muskegon 122 cm line; meter not repairable; flow calculated by deducting all other flows from total flow at the treatment site
– installation of additional cooling pipe on each pump to improve cooling

Lift Station D (61.44 TCMD).
– repair of broken shafts on pumps 2 and 4
– balance of impeller on pump 4
– installation of a new coupling between the motor and the pump to reduce vibration in pump 4
– installation of an auxillary generator to prevent spillage in the event of power failure
– installation of larger capacity spillway to Ruddiman Drain
– installation of concrete pads for generator
– installation of "lock out" locks on the main power breaker and in the main power box to D-station to prevent crossfeed from one power source to the other
– replacement of check valves with side-plug assemblies to correct chronic leaking onto the pump room floor
– repair temporarily the air-vacuum relief valve to the 91 cm sewer line until it can be replaced during favorable weather

Lift Station F (0.34 TCMD).
- installation of water filters on tubing going to mechanical seals
- correction of leak around the housing of pump number 3 by shimming of impeller to provide clearance
- installation of hinged access cover in the drop chamber on the incoming gravity sewer
- installation of stainless steel basket to screen debris from pump portal
- construction of a copper dam around the overflow pipe from the wet well to prevent debris accumulation and to allow the cover to properly open and seal
- repair a leak in the force main along Airline Road by the installation contractor under warranty; cause was a rolled gasket at a pipe joint

Lift Station H (5.49 TCMD).
- correction of plugged pumps due to small patches and lumps of cloth
- correction of plugged airline bubble on level control mechanism

Lift Station J (0 TCMD) No sewer system. Routine inspection only.

Lift Station K (1.13 TCMD)
- installation of mechanical seal in variable speed pump
- replacement of automatic greaser by manual procedure
- replacement of air compressor relay
- replacement of time-delay relay on variable speed pump

Lift Station L (0.31 TCMD).
- clean (twice) electric probes on level controls
- removal of sand from ventilation pipe, probably caused by vandals
- restoration of power by the power company when one of the primary leads to the transformer became detached

B. Aeration Equipment

The types of maintenance and repair problems in the biological treatment cells in 1975 are listed by cell.

Cell Number 1:
- no repairs on the twelve aerators (Aerator number 4 was transferred to the Whitehall subsystem in July, 1975.)
- repair of three mixers: No. 1 lost propeller blade and stabilizer fins; No. 2 loose platform mounting bolts; No. 4 sheared platform mounting bolts

Cell Number 2:
- replacement of burned motor leads on two aerators
- malfunction of two mixers because of vibration and noise; not repaired in 1975
- malfunction of one mixer because of burned out motor in 1974; not repaired

Cell Number 3:
- repair locked rotor on aerator
- shutdown of one aerator due to excessive noise
- shutdown of two aerators due to excessive vibration

C. Irrigation Pump Maintenance

- repair of a bus bar short at the south station, May, 1974
- repair of separated overhead transmission line to the north station, November, 1974
- inspection and repair of all irrigation pumps after the 1974 irrigation season

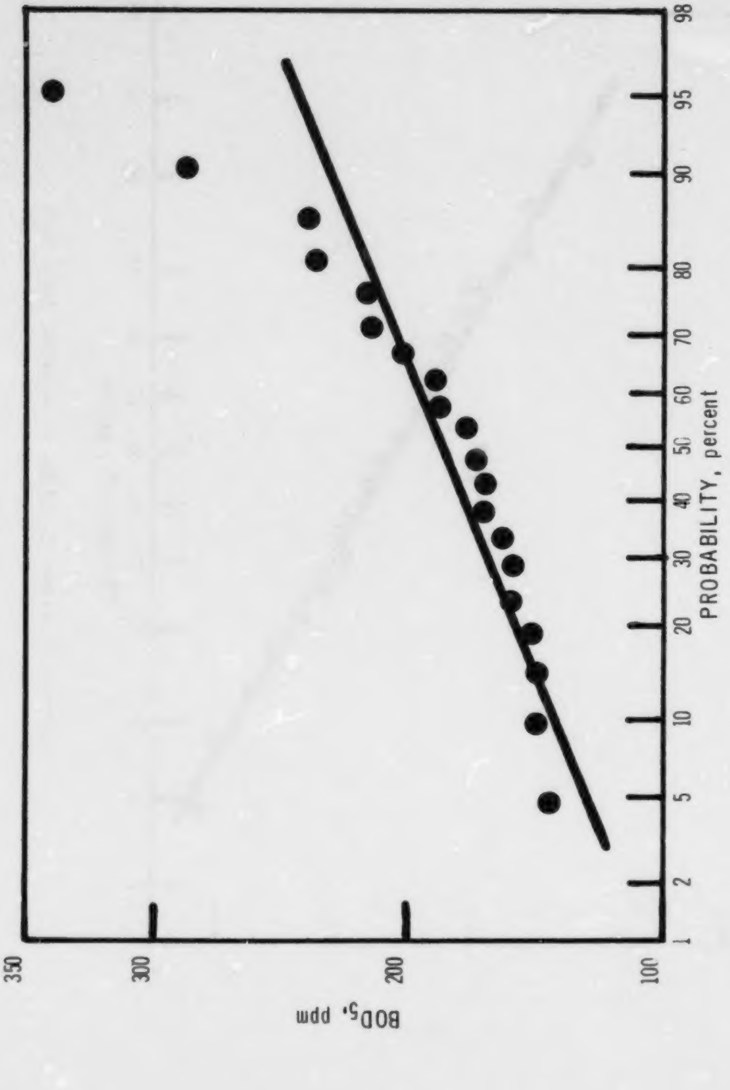
Appendix B, Table 1. WMS MONTHLY INFLUENT FLOW, 1973-1975, TCM

	Year		
Month	1973	1974	1975
January	--	3156	3022
February	--	2809	2775
March	--	3278	2652
April	--	3198	2801
May	--	3301	3009
June	--	3412	3007
July	3279	3116	2830
August	3354	3454	3144
September	3133	3014	3088
October	3177	3145	3241
November	2965	3088	3038
December	2893	2792	2904

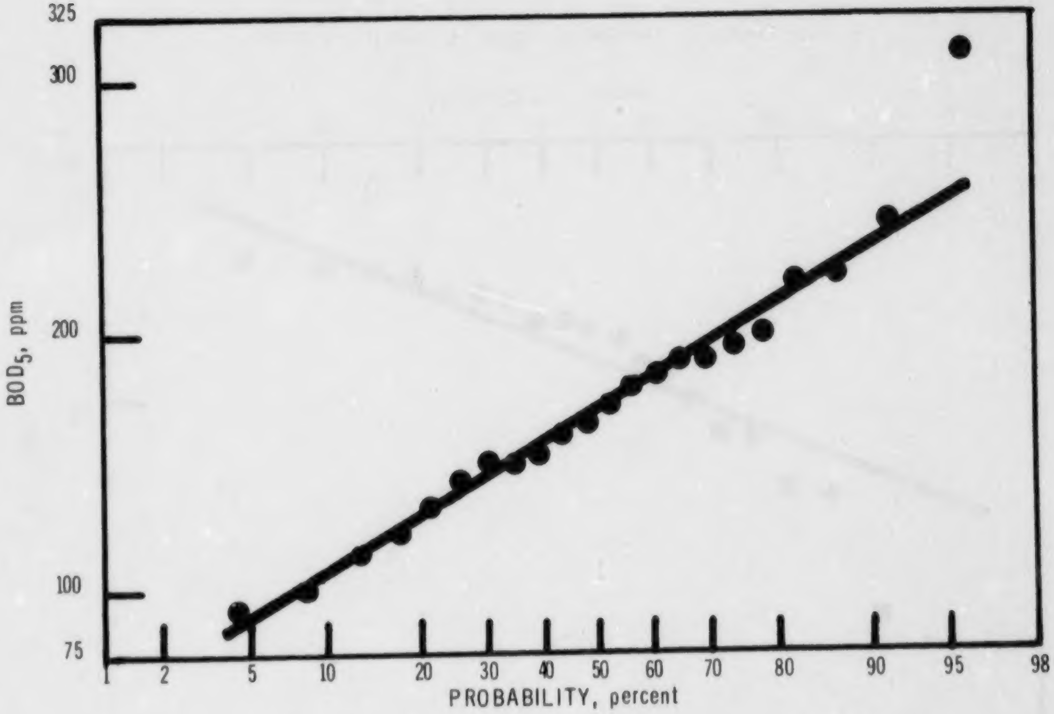
Appendix B, Table 2. IRRIGATION PUMP STATION MAINTENANCE

	1975 maintenance and repair			
		Stuffing box		
Station and pump number	Headshaft metalized	Cleaned & repacked	New bushings	Other
North station[a]				
1	×	×	×	Lower motor bearing replaced
2	×	×	×	Lower motor bearing replaced
3		×		
4		×		
5	×	×	×	Lower motor bearing replaced
6		×		
7		×		
8		×		
9	×	×	×	
10	×	×	×	Lower motor bearing replaced
South station				
1		×		
2		×		
3		×		
4		×		
5		×		
6		×		
7		×		
8		×		
9		×		
10		×		
11		×		

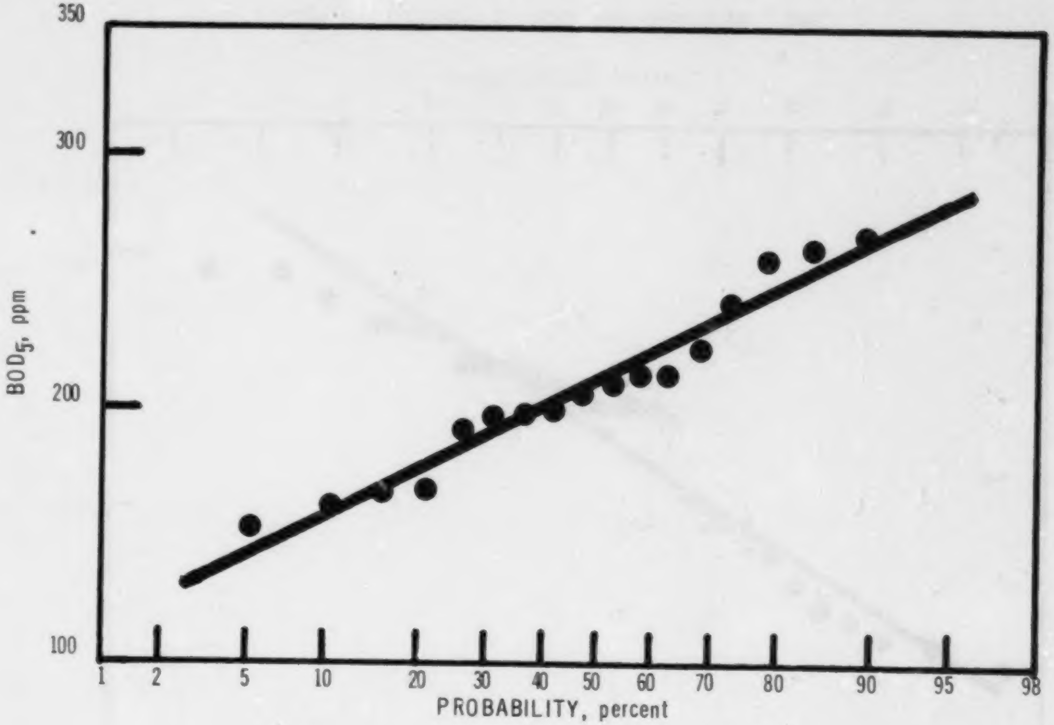
[a] Operational pumping was twice the volume of the south station.



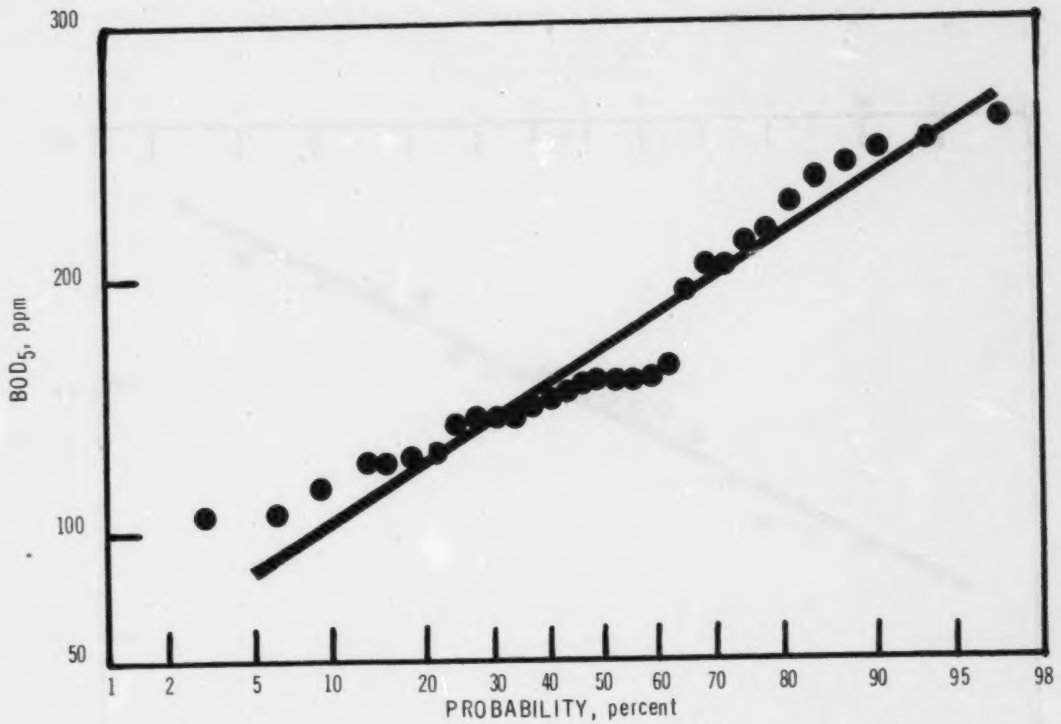
Appendix C, Figure 1. BOD$_5$ in influent, February, 1974



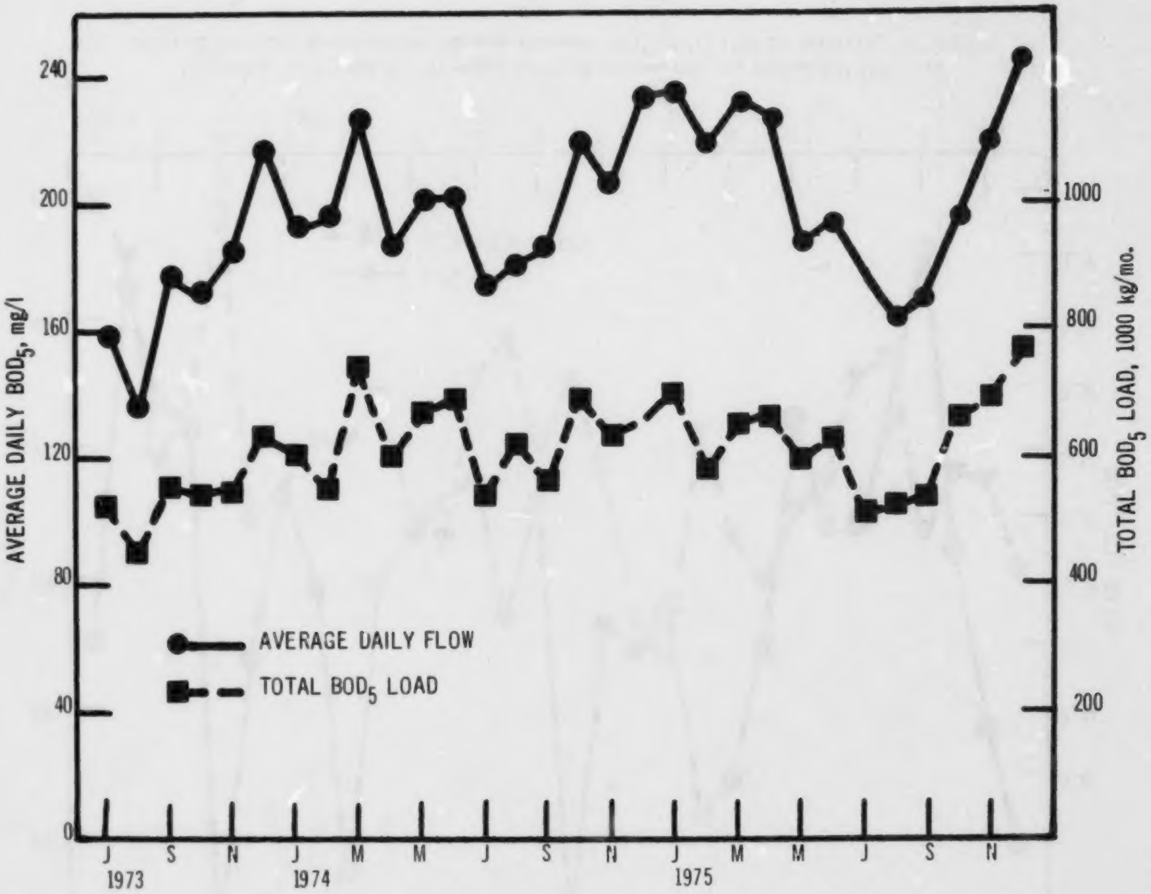
Appendix C, Figure 2. BOD$_5$ in influent, July, 1974



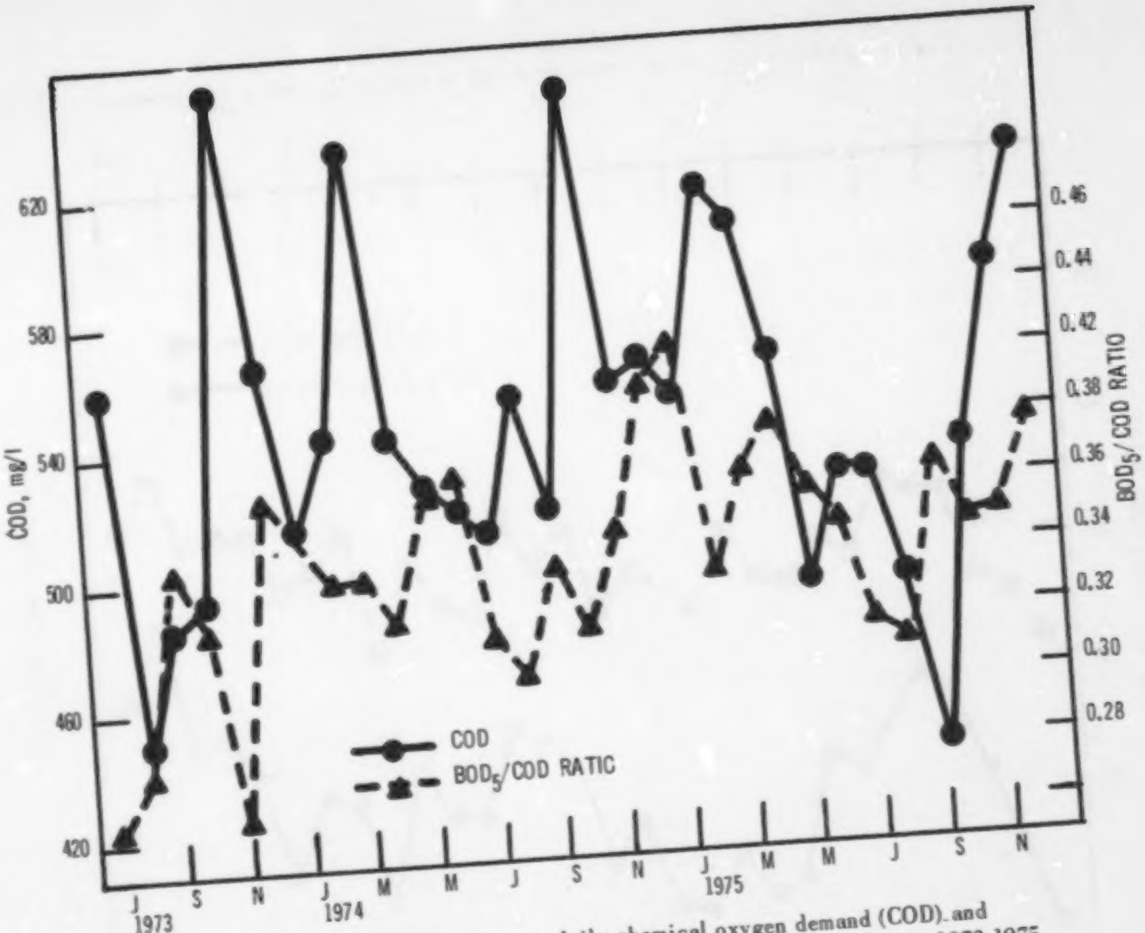
Appendix C, Figure 3. BOD_5 in influent, February, 1975



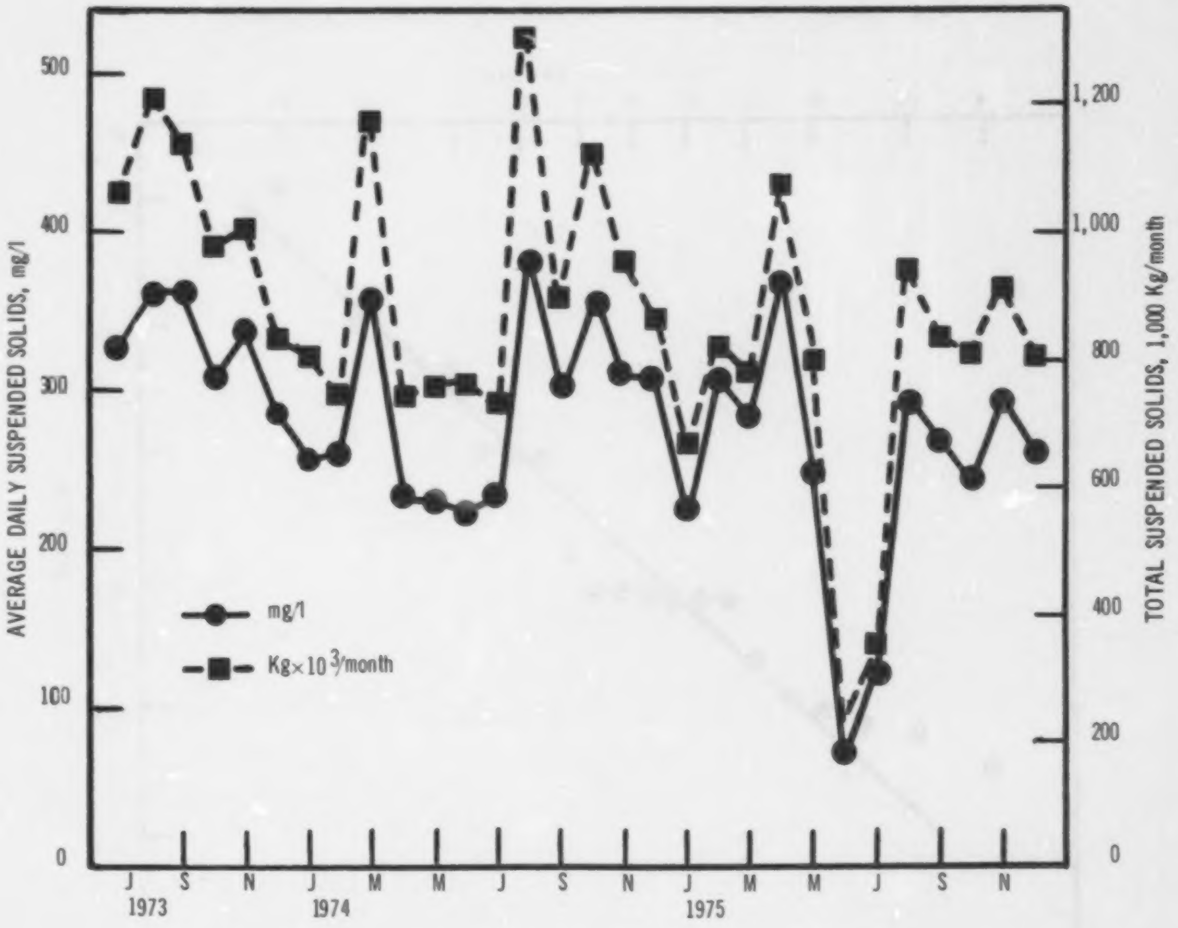
Appendix C, Figure 4. BOD$_5$ in influent, July, 1975



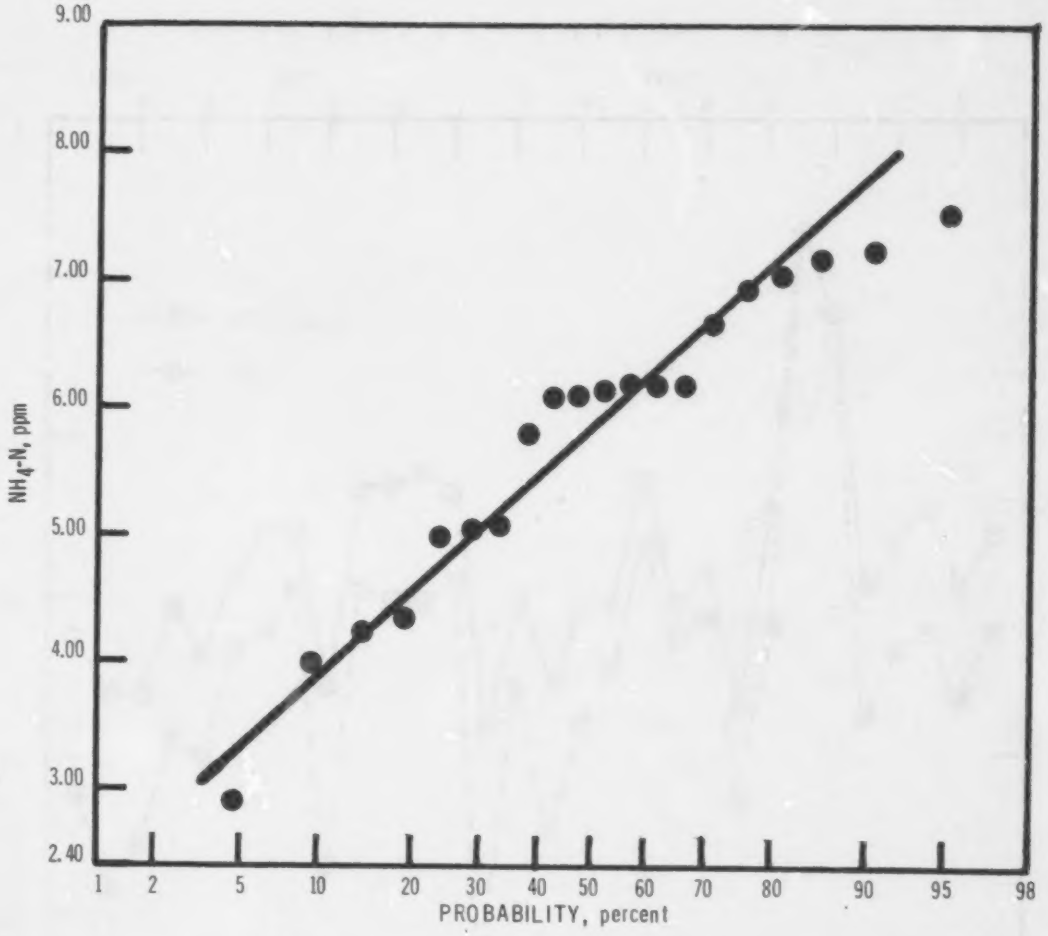
Appendix C, Figure 5. Total five-day biochemical oxygen demand and flow rate of influent, 1973-1975



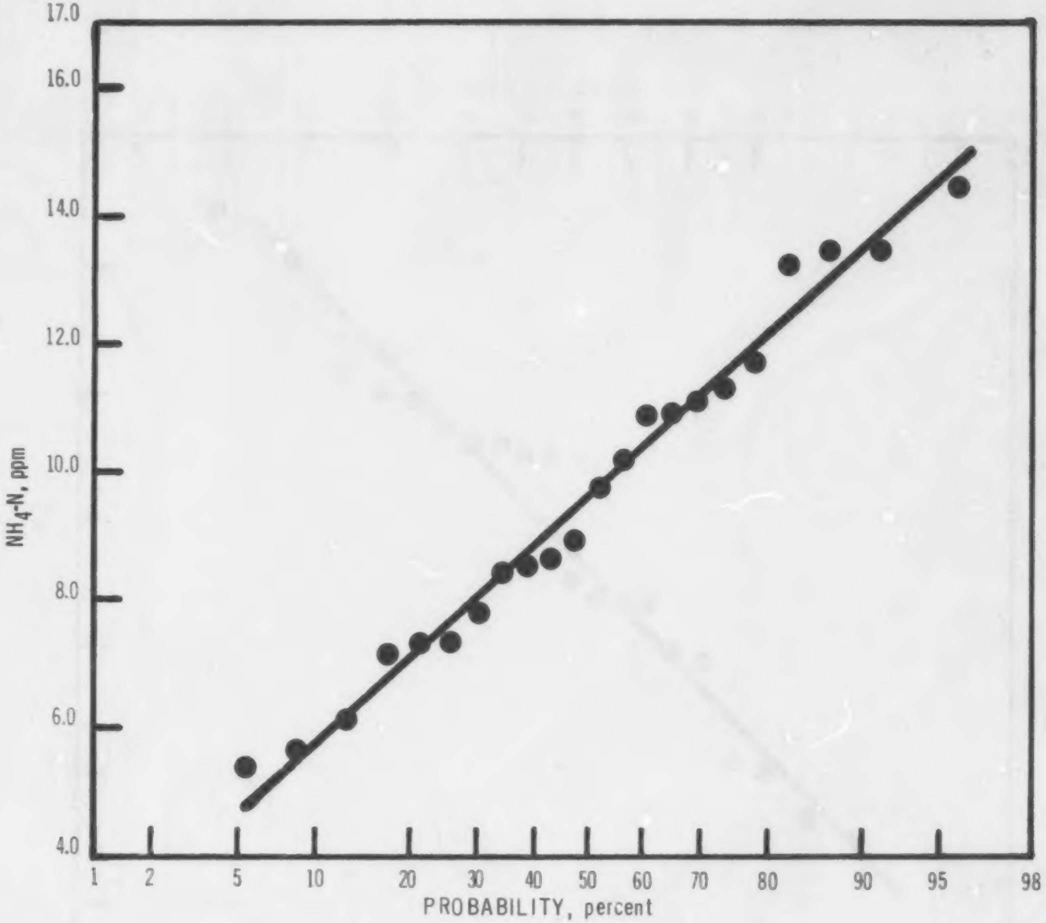
Appendix C, Figure 6. Average daily chemical oxygen demand (COD) and ratio of five-day biochemical oxygen demand (BOD$_5$) / (COD) in influent, 1973-1975



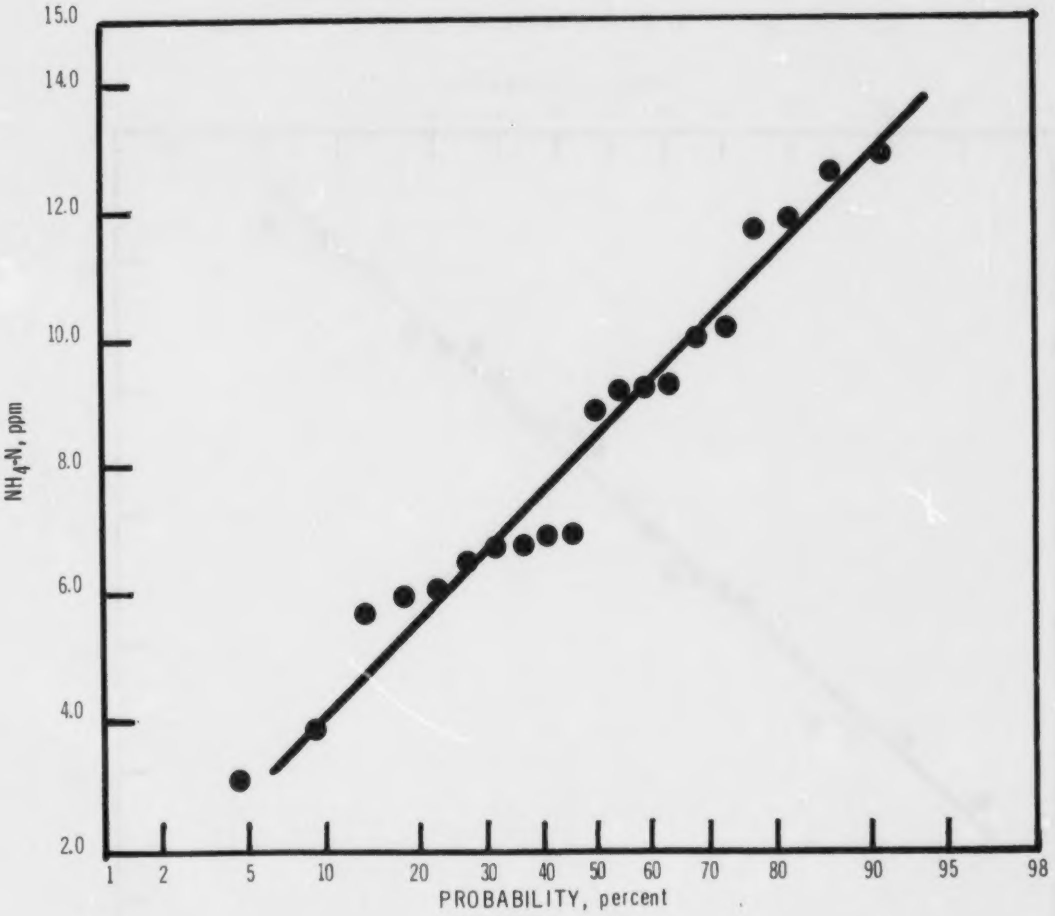
Appendix C, Figure 7. Suspended solids in influent, 1973-1975



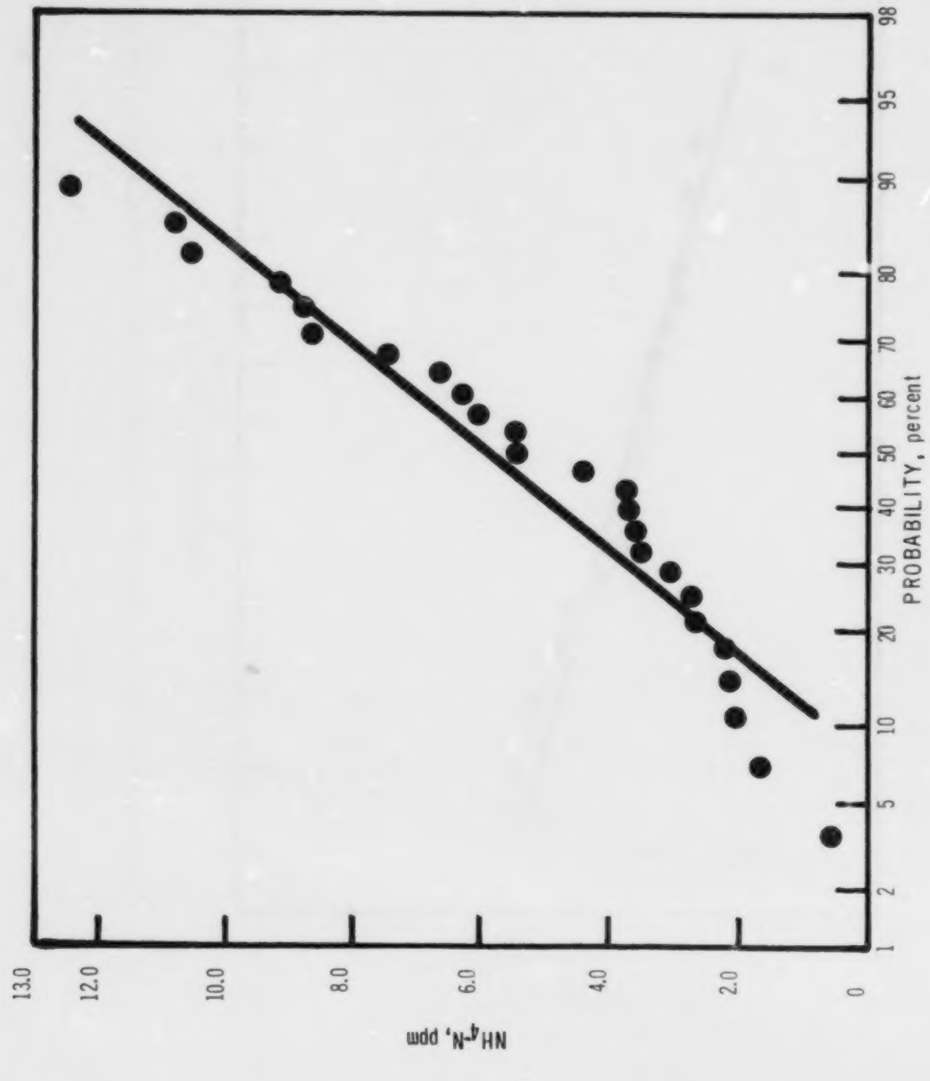
Appendix C, Figure 8. Ammonium nitrogen in influent, February, 1974



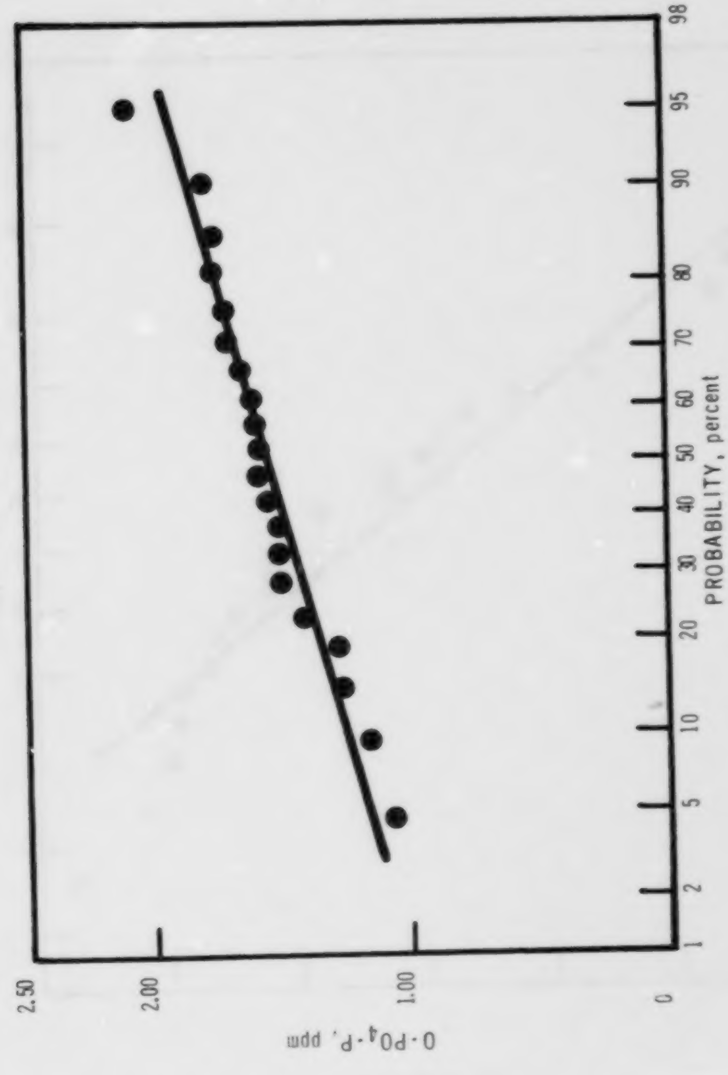
Appendix C, Figure 9. Ammonium nitrogen in influent, July, 1974



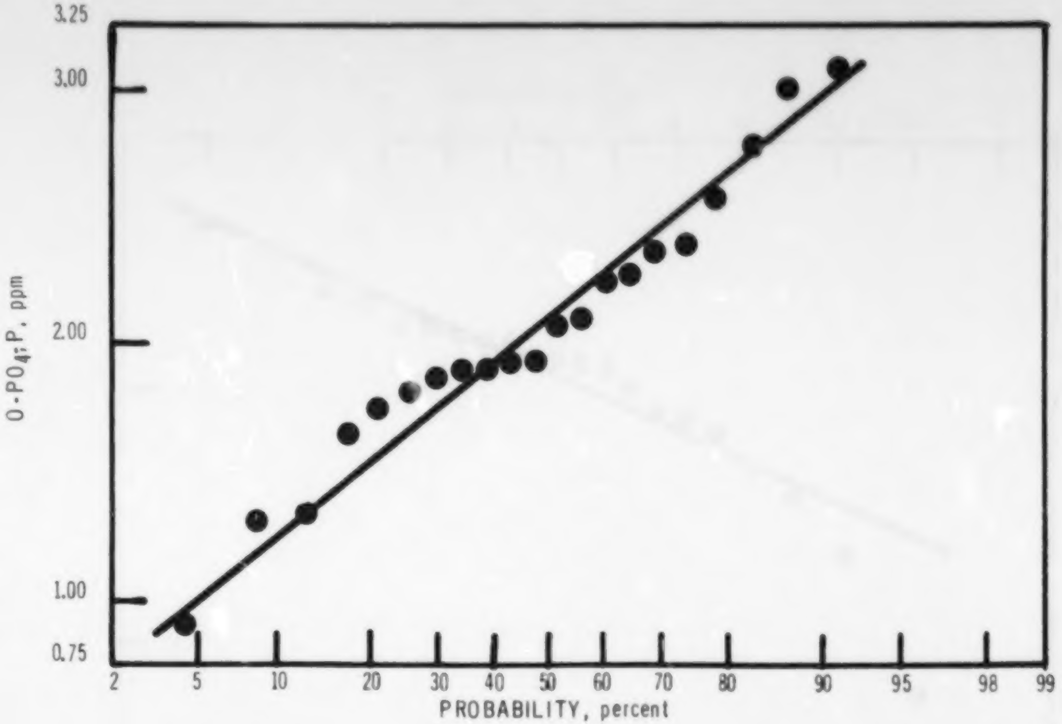
Appendix C, Figure-10. Ammonium nitrogen in influent, February, 1975



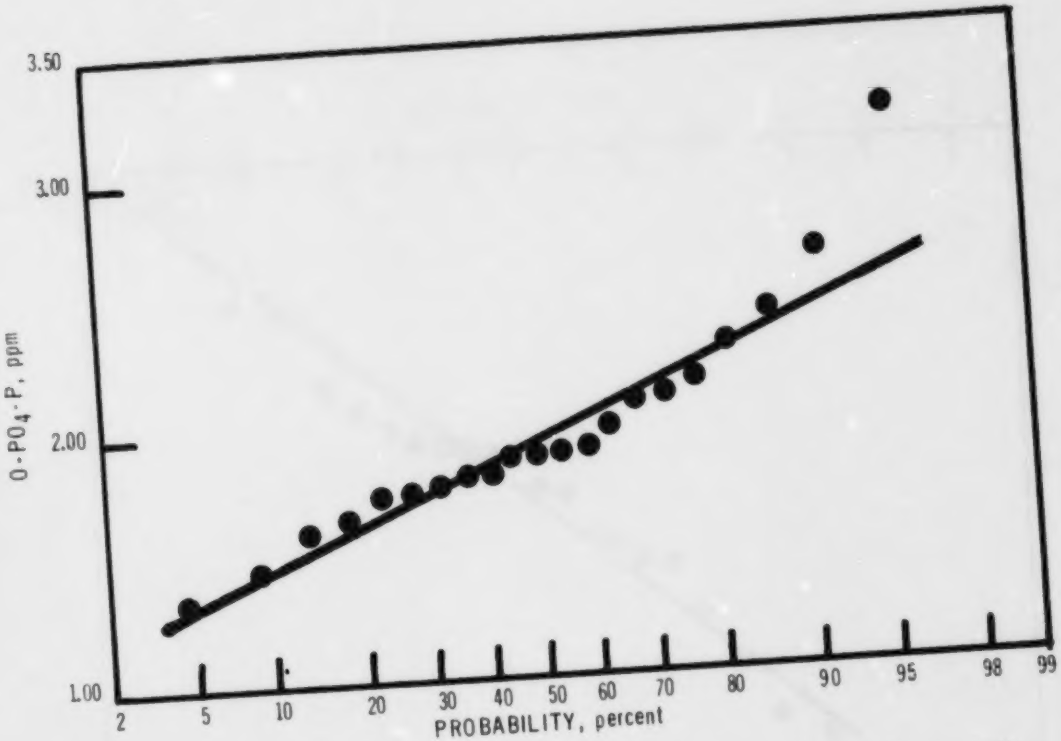
Appendix C, Figure 11. Ammonium nitrogen in influent, July, 1975



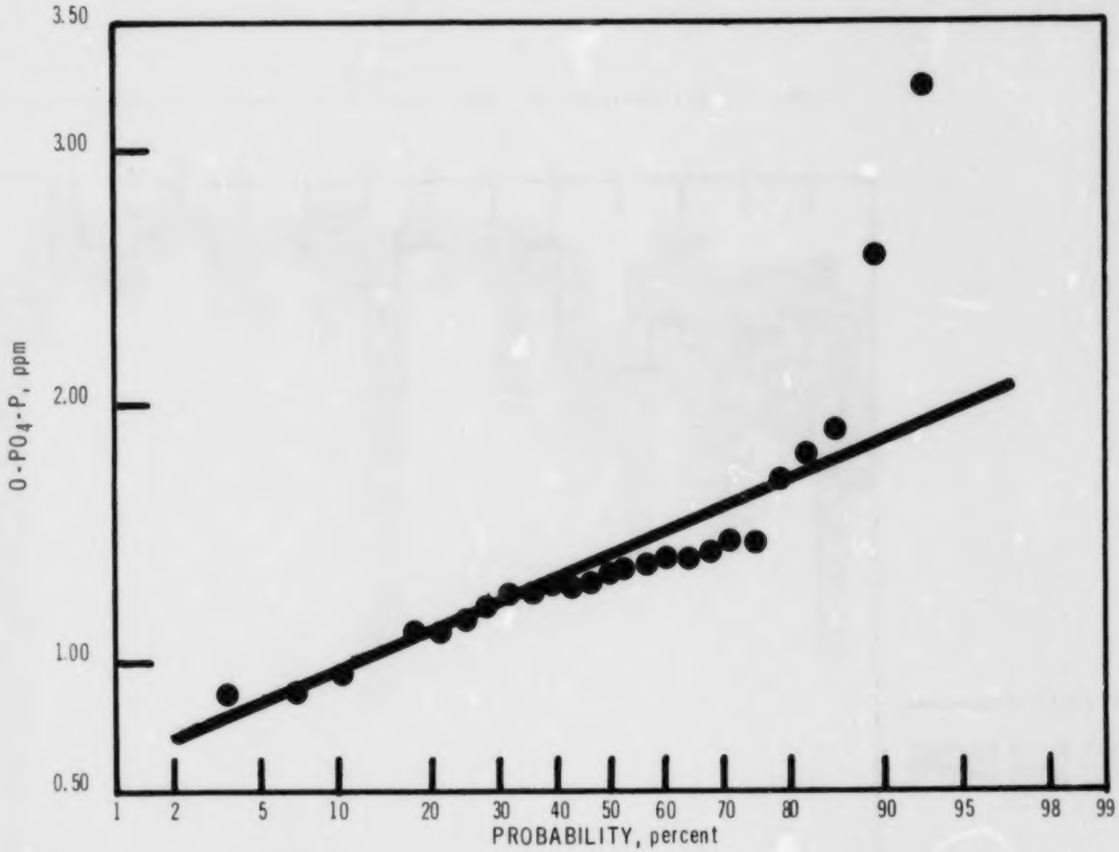
Appendix C, Figure 12. Phosphorus (ortho-phosphate) in influent, February, 1971



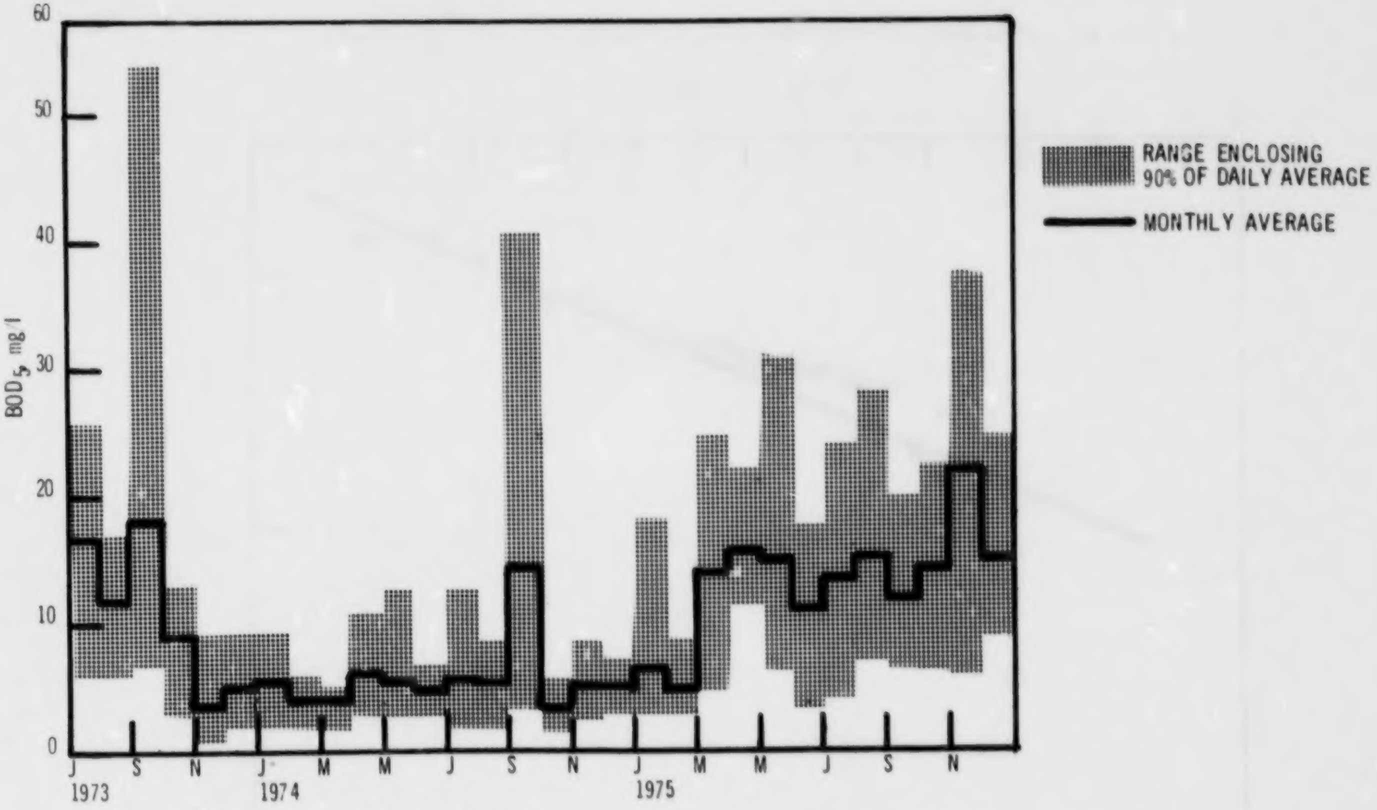
Appendix C, Firgure 13. Phosphorus (ortho-phosphate) in influent, July, 1974



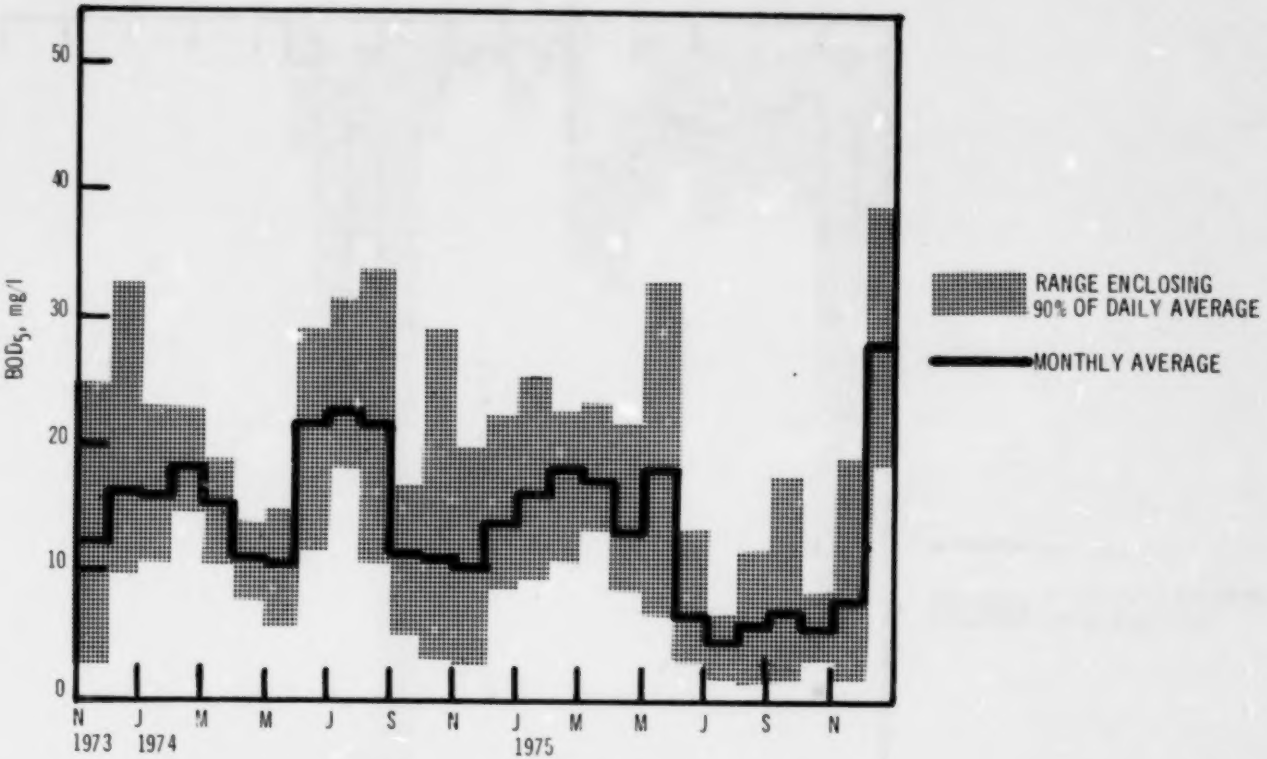
Appendix C, Figure 14. Phosphorus (ortho.phosphate) in influent, February, 1975



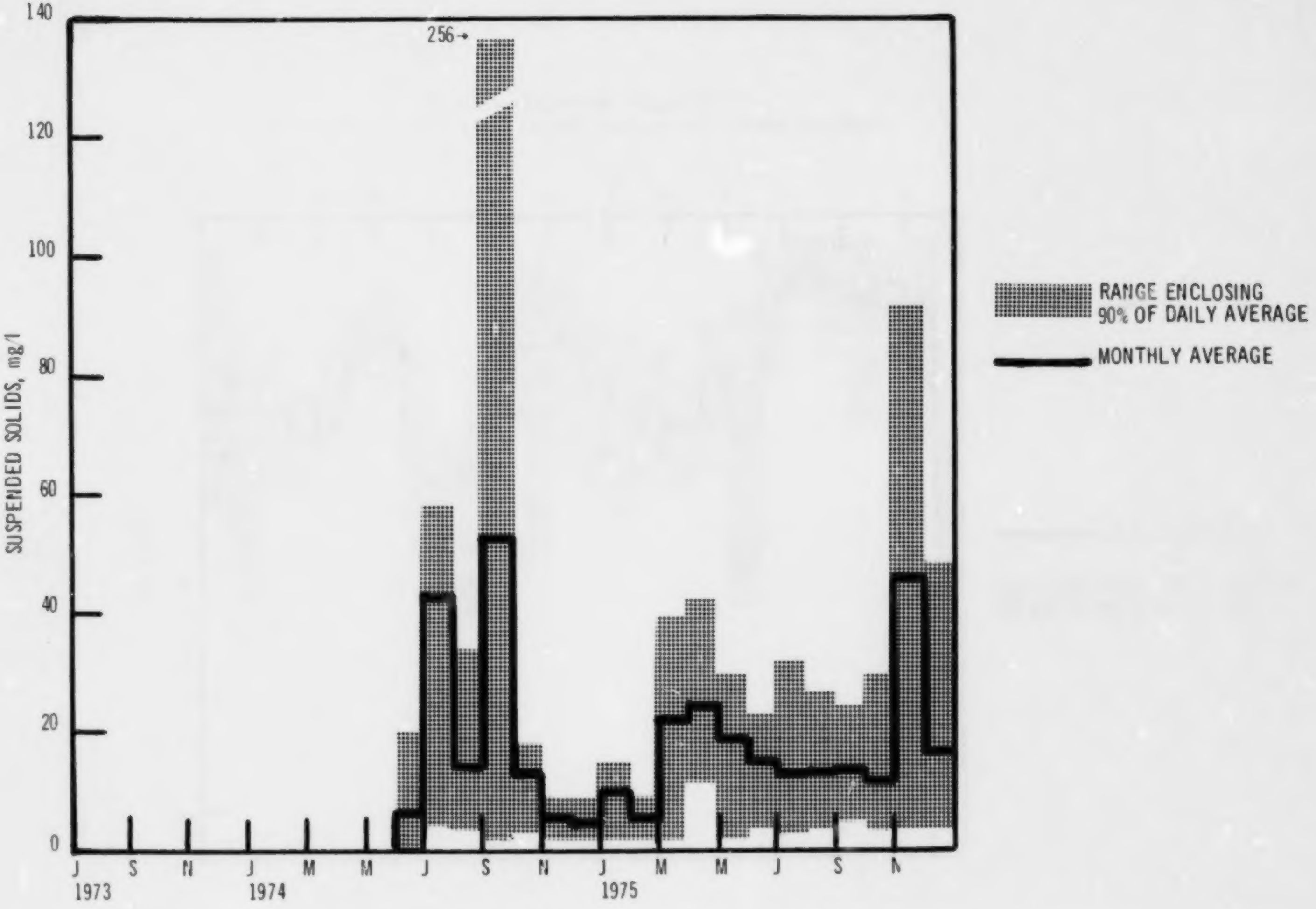
Appendix C, Figure 15. Phosphorus (ortho-phosphate) in influent, July, 1975



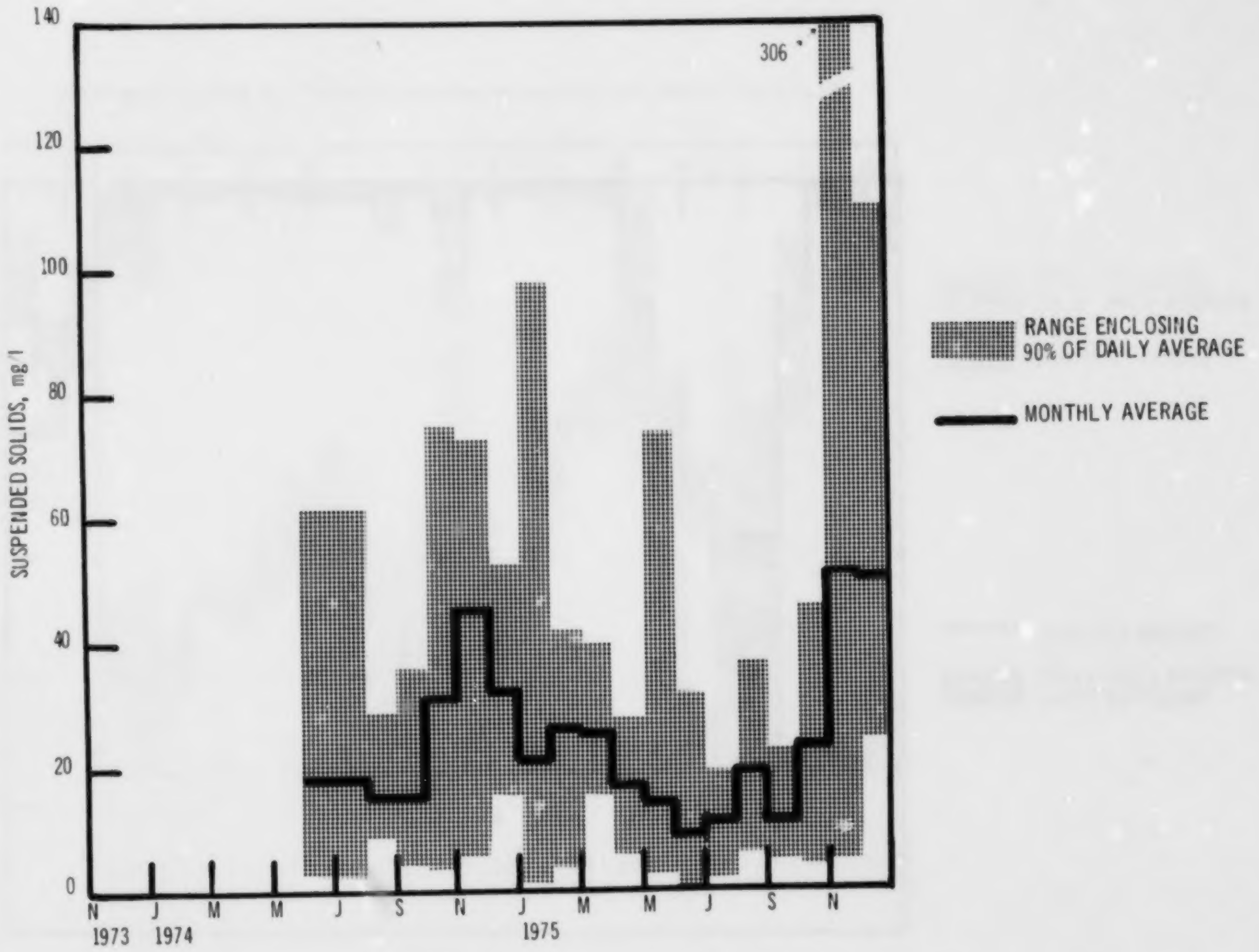
Appendix C, Figure 16. Five-day biochemical oxygen demand in west storage lagoon, 1973-1975



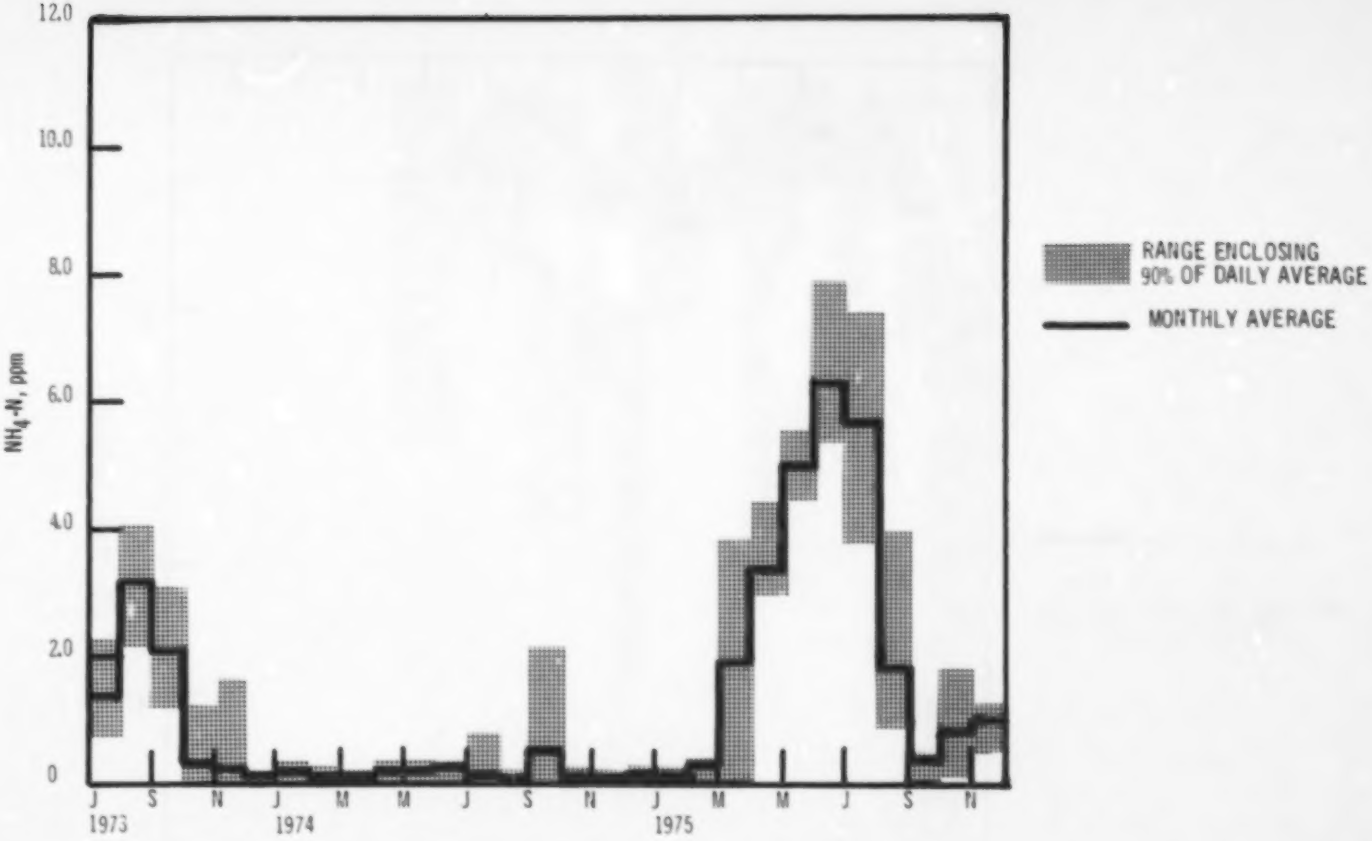
Appendix C, Figure 17. Five-day biochemical oxygen demand in east storage lagoon, 1973-1975



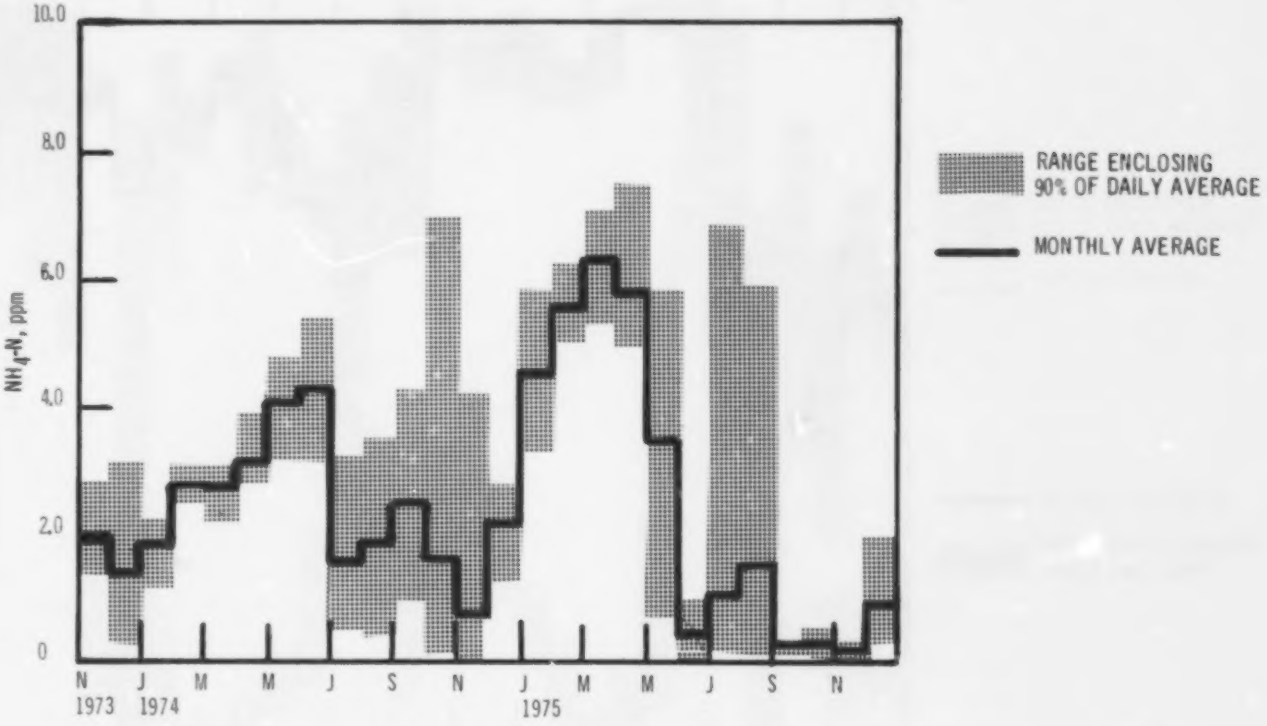
Appendix C, Figure 18. Suspended solids in west storage lagoon, 1974-1975



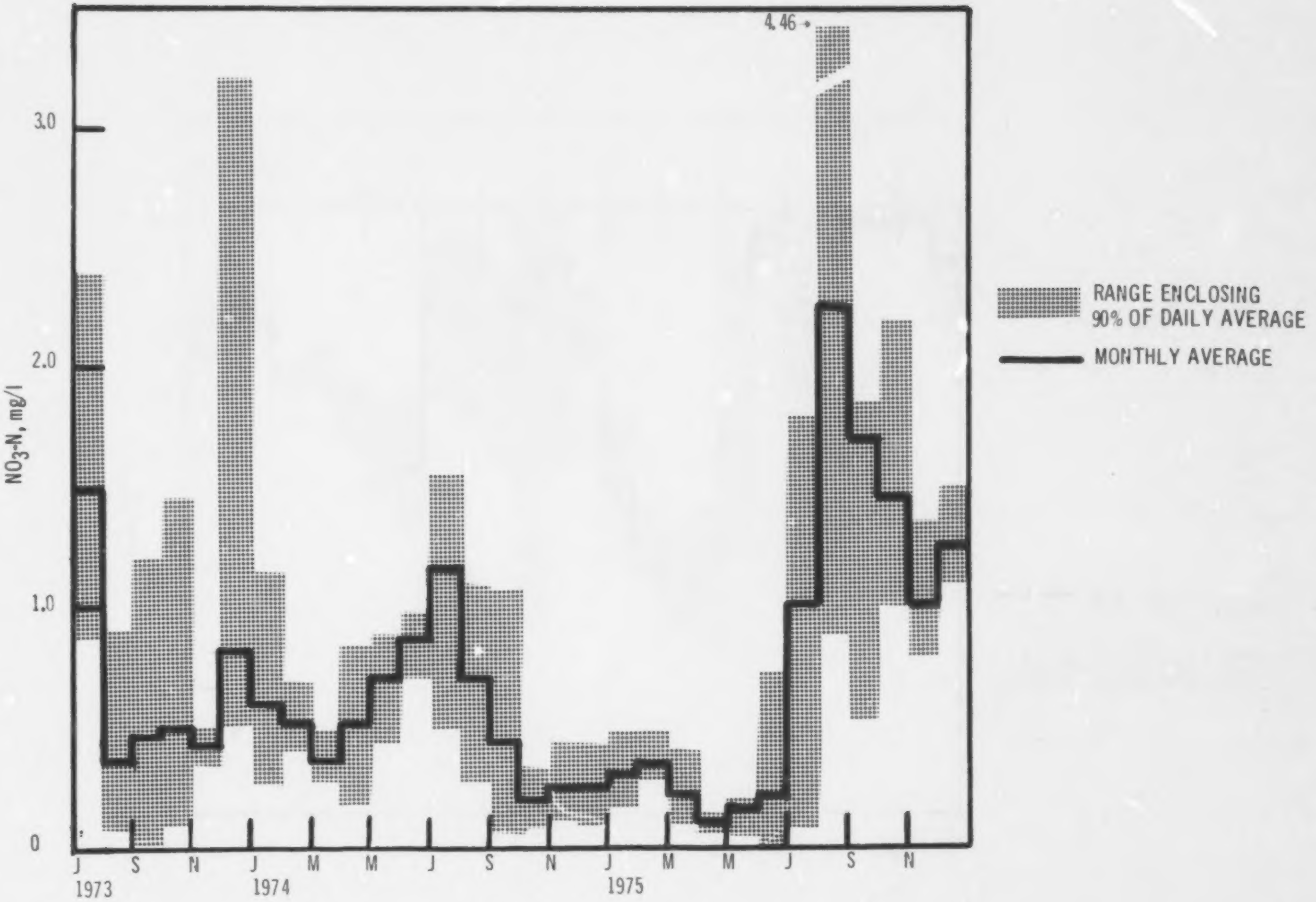
Appendix C, Figure 19. Suspended solids in east storage lagoon, 1974, 1975



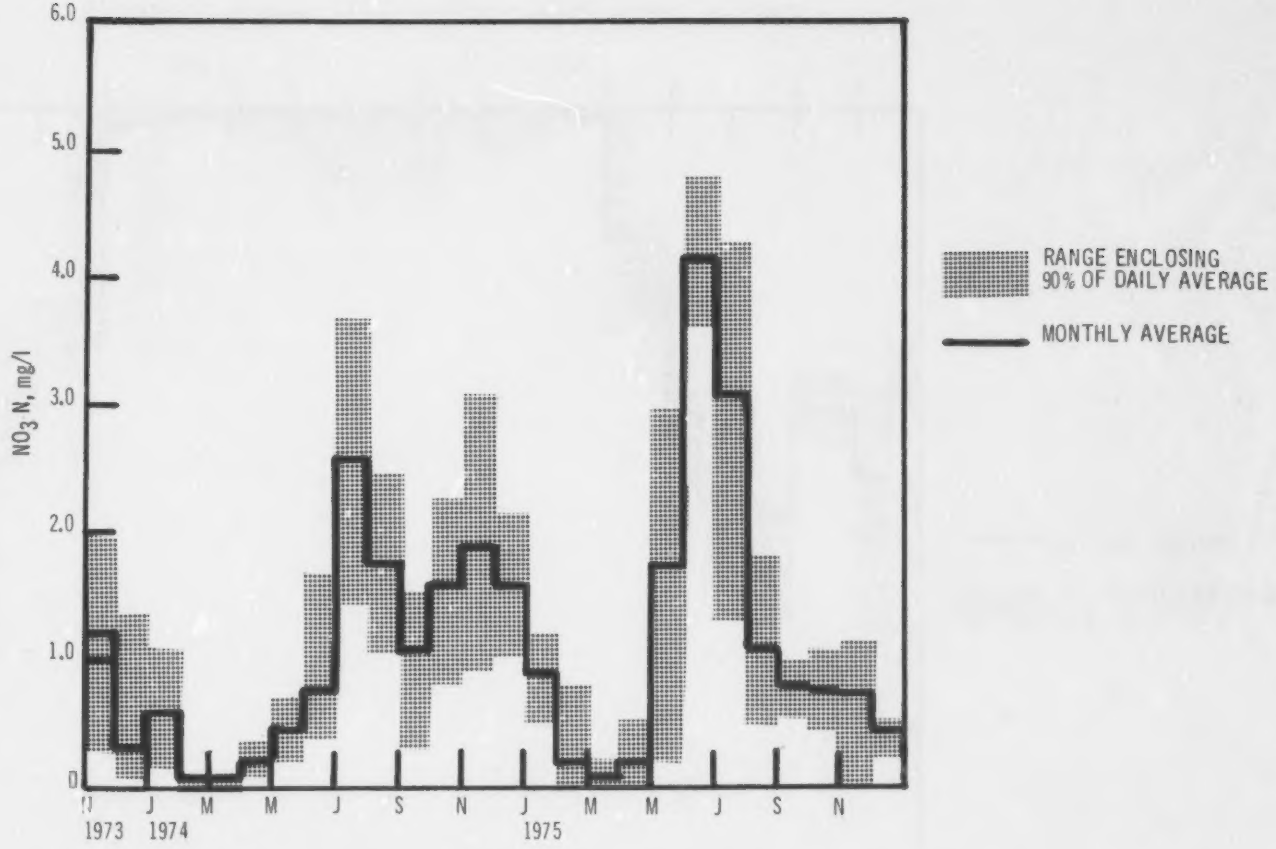
Appendix C, Figure 20. Ammonia nitrogen in west storage lagoon, 1973-1975



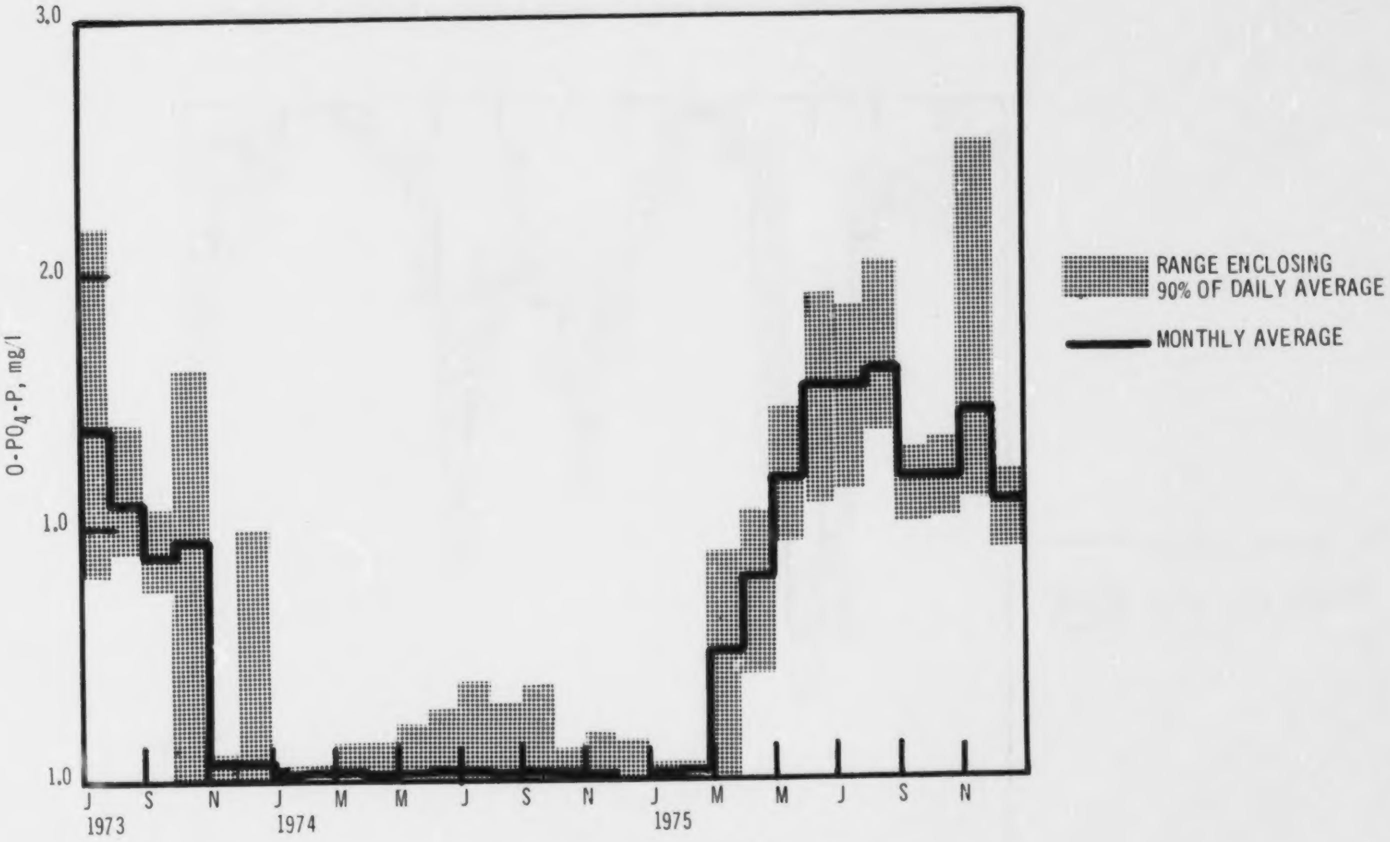
Appendix C, Figure 21. Ammonia nitrogen in east storage lagoon, 1973-1975



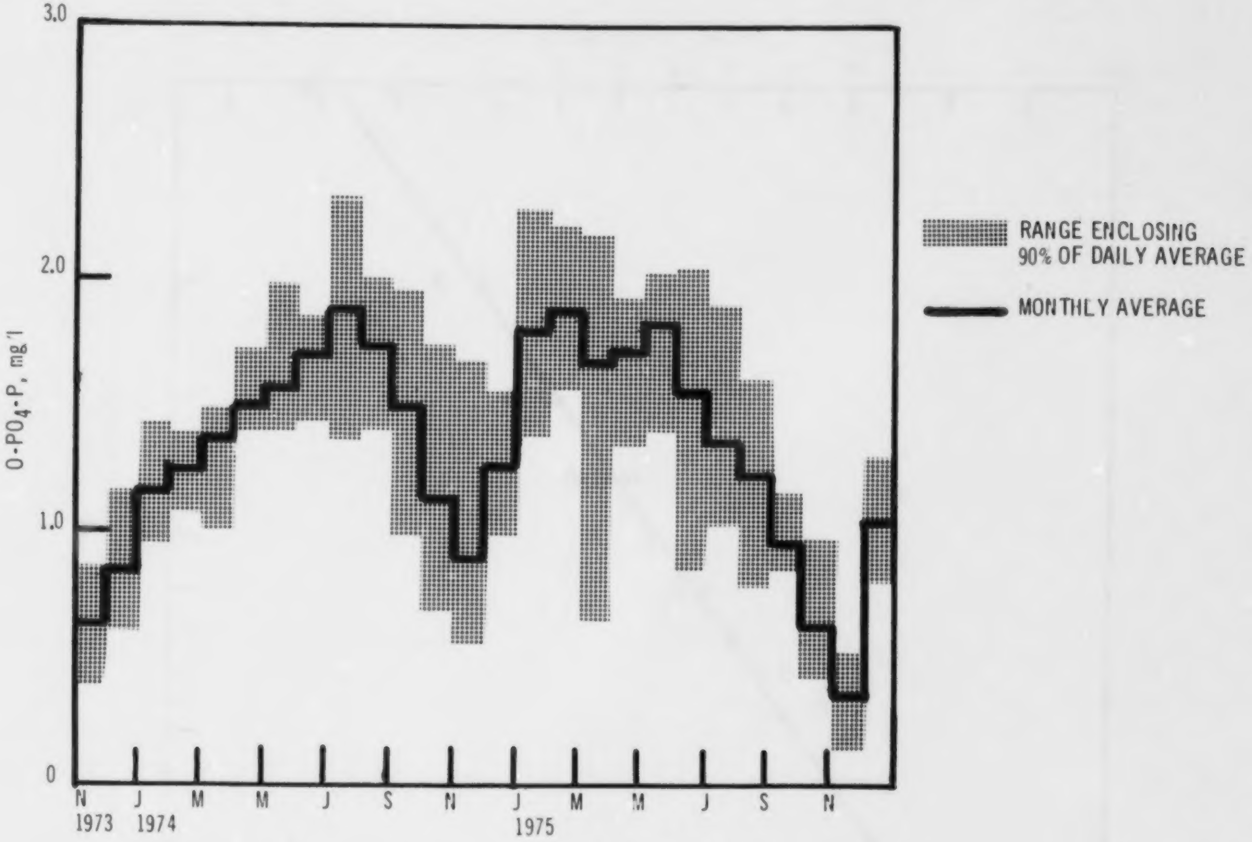
Appendix C, Figure 22. Nitrate nitrogen in west storage lagoon, 1973-1975



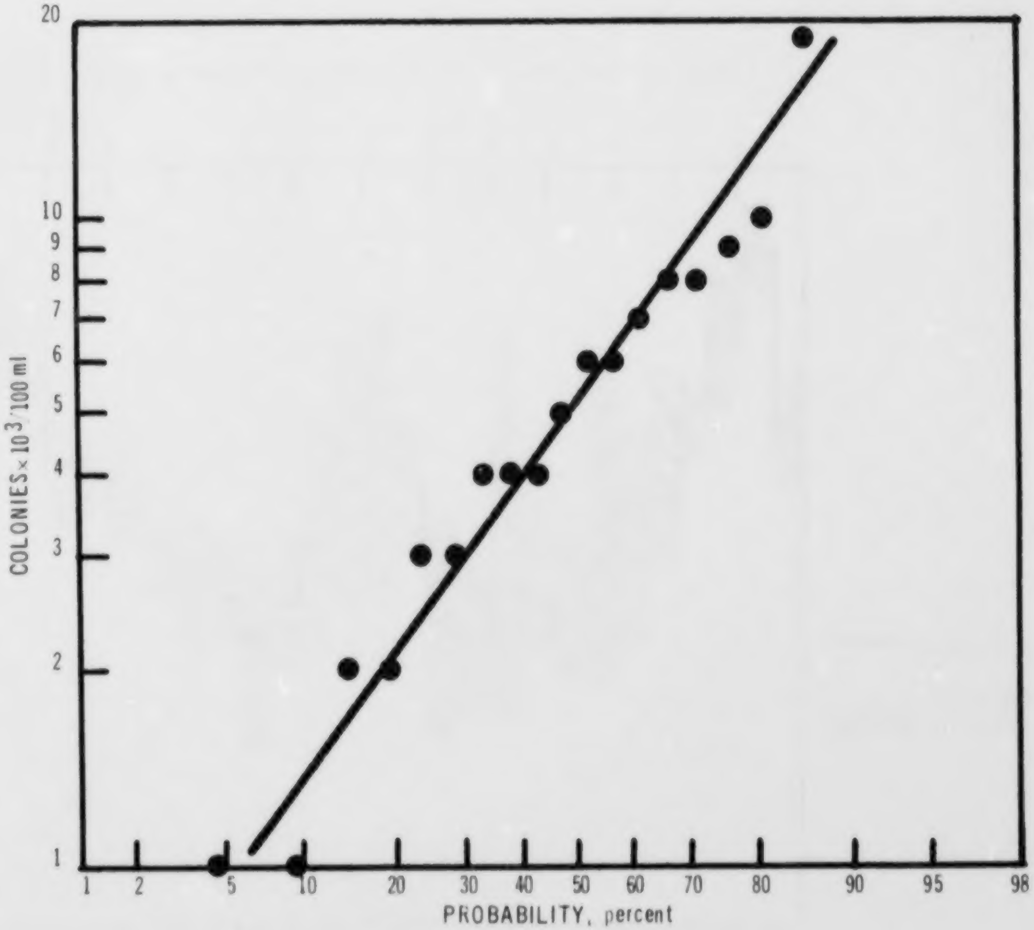
Appendix C, Figure 23. Nitrate nitrogen in east storage lagoon, 1973-1975



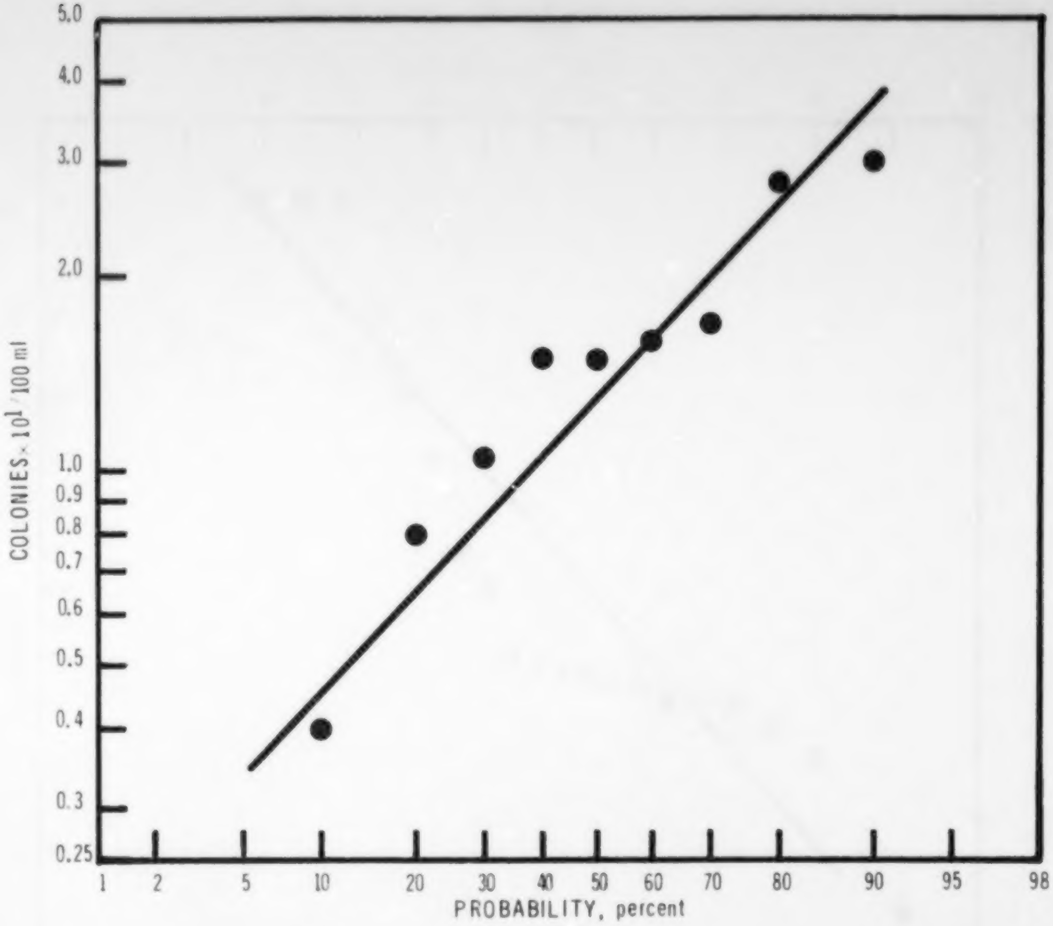
Appendix C, Figure 21. Phosphate in west storage lagoon, 1973-1975



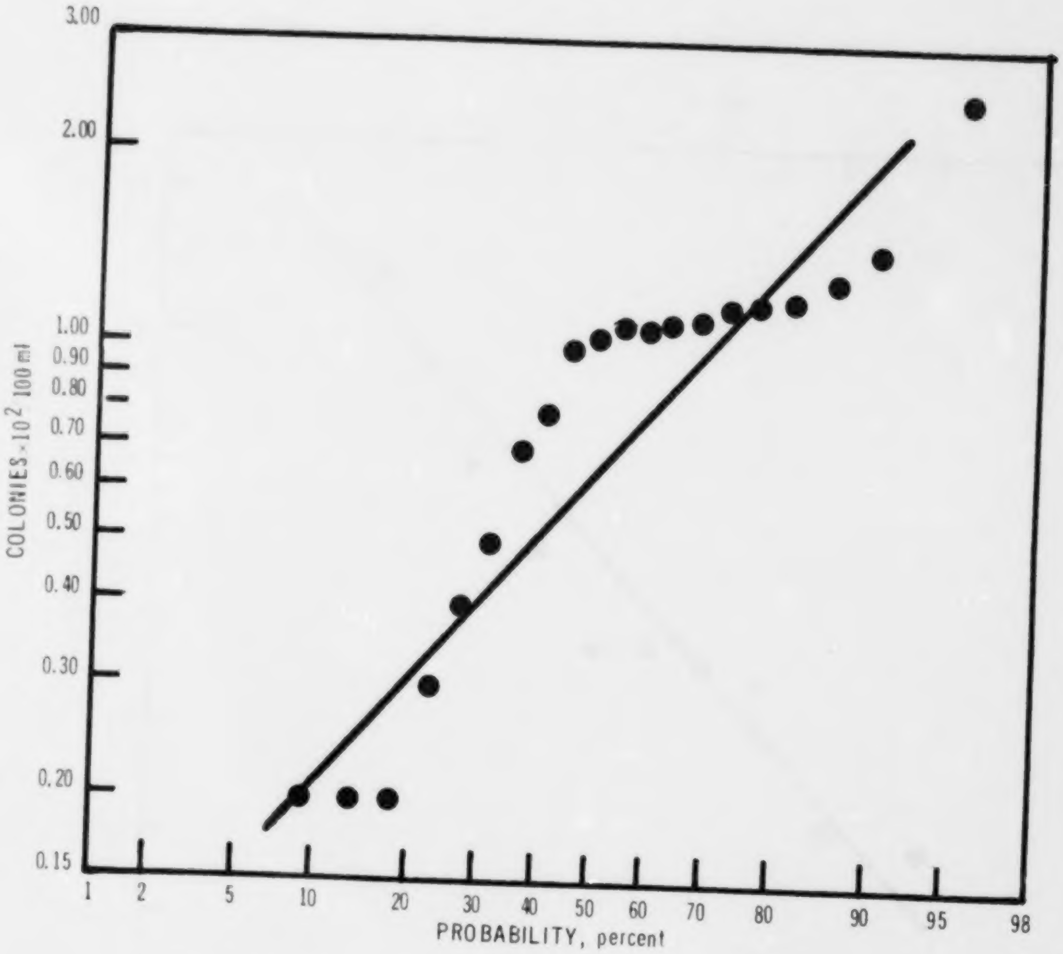
Appendix C, Figure 25. Phosphate in east storage lagoon, 1973-1975



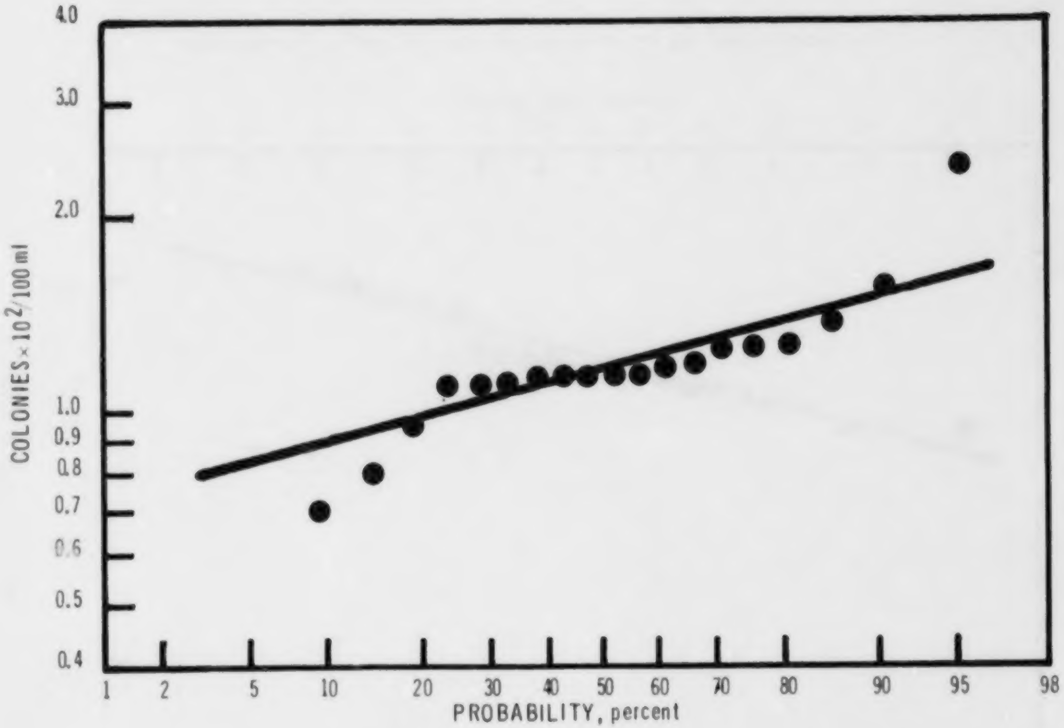
Appendix C, Figure 26. Fecal coliform in east storage lagoon, March, 1975



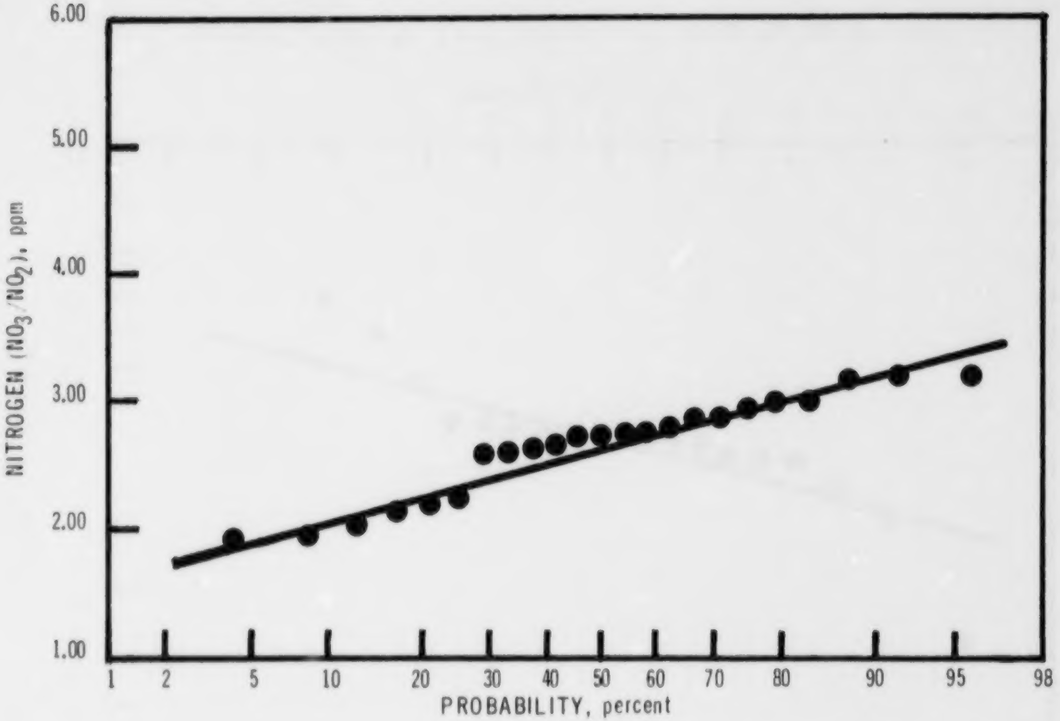
Appendix C, Figure 27. Fecal coliform in east storage lagoon, April, 1975



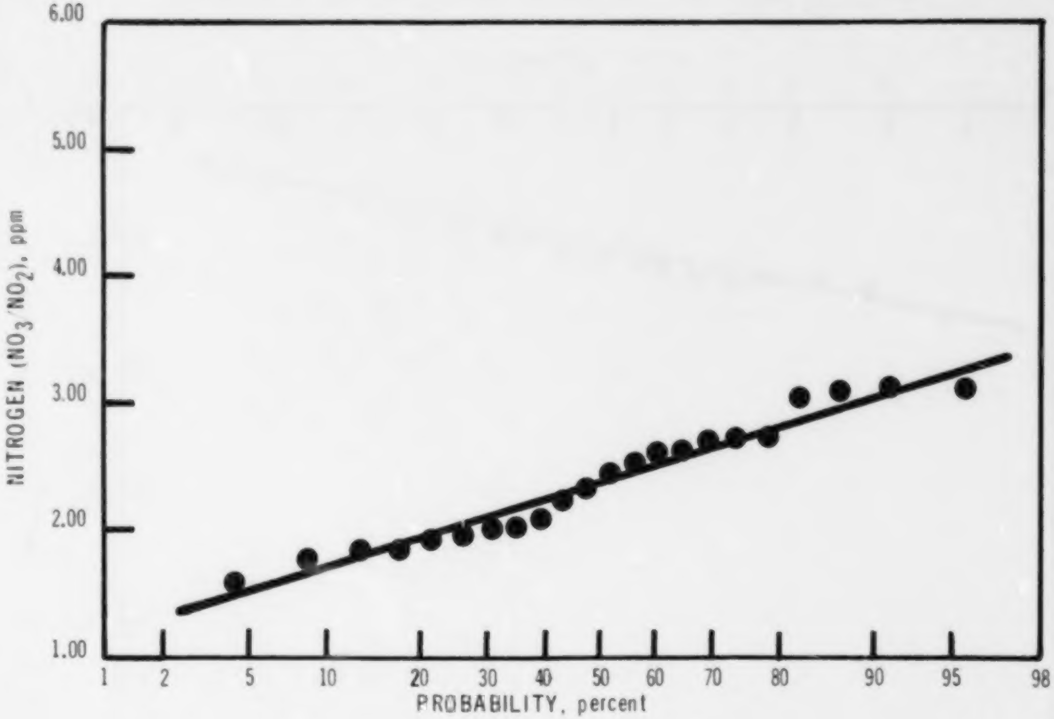
Appendix C, Figure 28. Fecal coliform in east storage lagoon, May, 1975



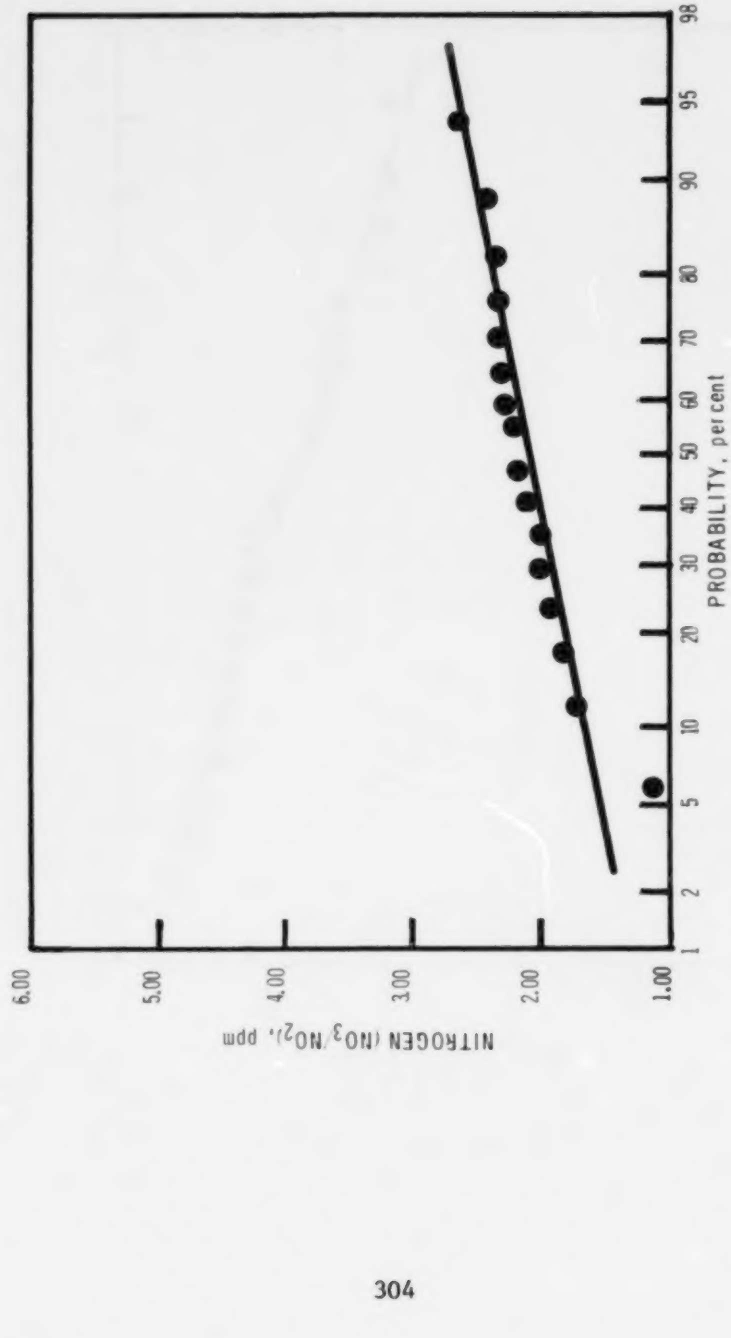
Appendix C, Figure 29. Fecal coliform in east storage lagoon, June, 1975



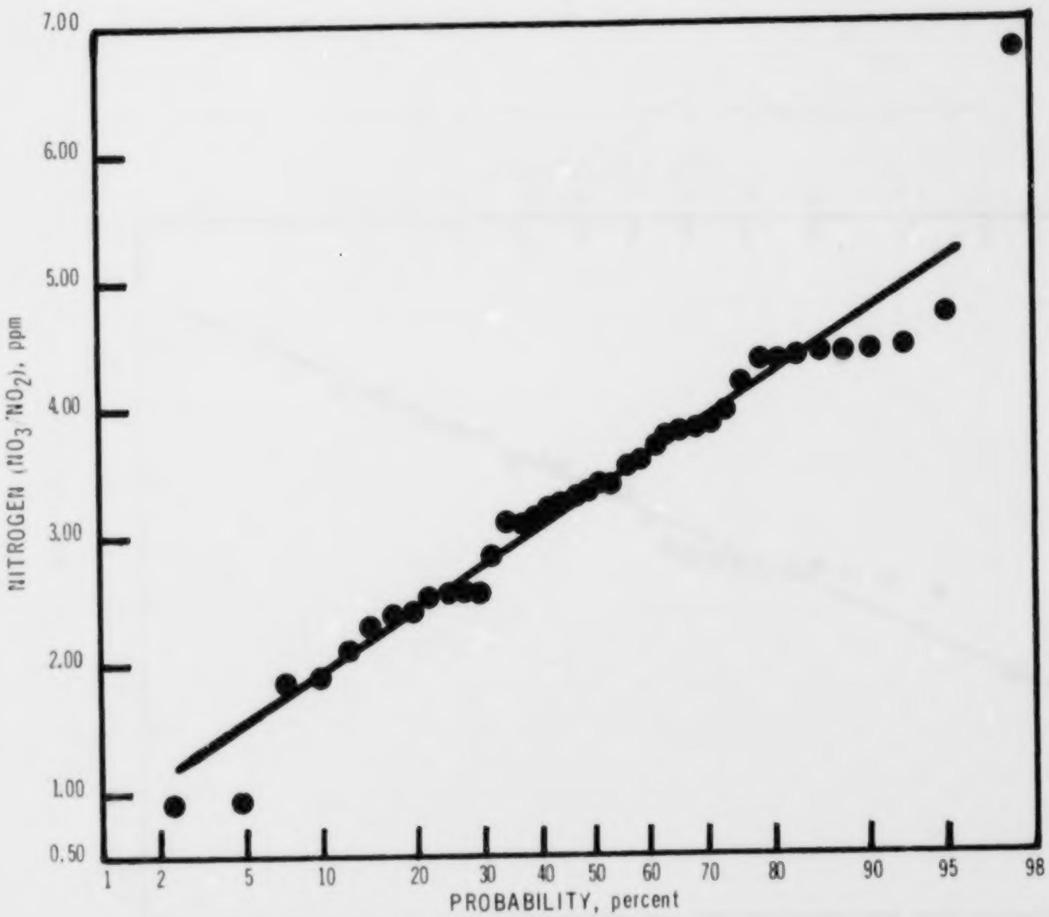
Appendix C, Figure 30. Nitrogen in drain tile 19, June-August, 1974



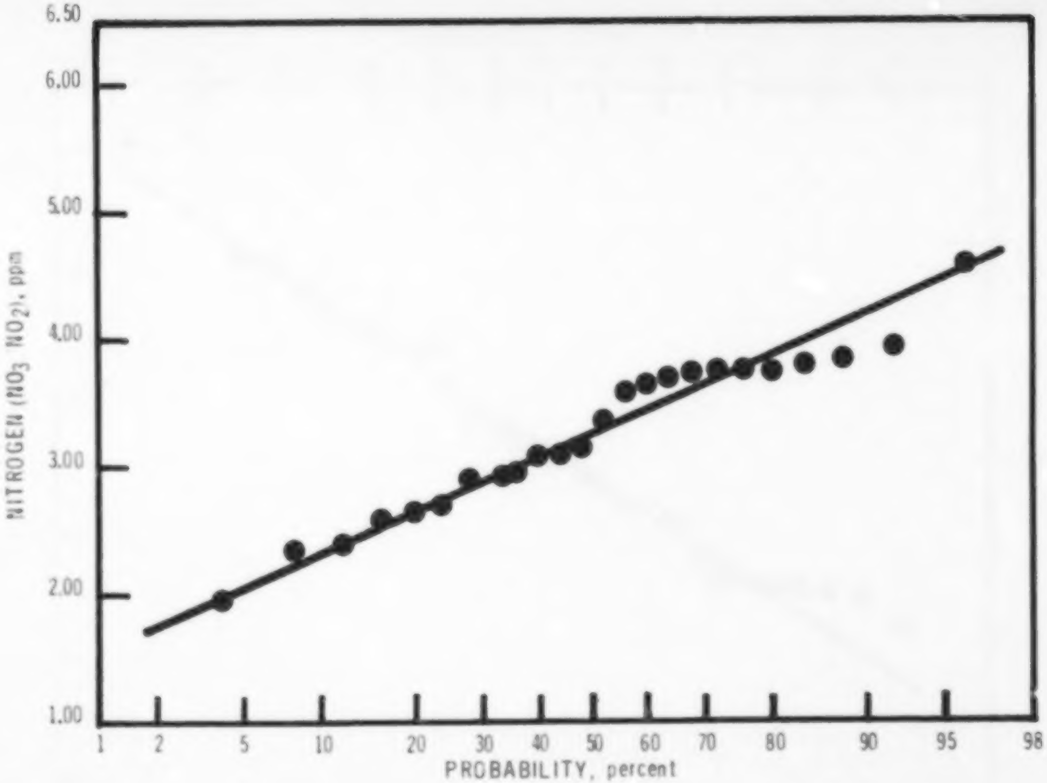
Appendix C, Figure 31. Nitrogen in drain tile 19, September-November, 1974



Appendix C, Figure 32. Nitrogen in drain tile 19, December, 1974-March, 1975



Appendix C, Figure 33. Nitrogen in drain tile 19, April-August, 1975



Appendix C, Figure 34. Nitrogen in drain tile 19, September-November, 1975

Appendix C, Table 1. TREATMENT PERFORMANCE SUMMARY MONTHLY AVERAGES FOR 1974 AND 1975 DRAIN TILE NUMBER 11

Year/ Month	BOD_5, ppm	pH, SU	Sp cond, μmhos/cm	Color, APHA	Turb, FTU	TOC, ppm	Parameters in ppm								
							NH_4	NO_3/NO_2-N	o-PO_4-P	SO_4	Cl	Na	Ca	Mg	K
1974															
Jun	1.00	7.40	289	13	0.80	5.30	0.02	1.75	0.01	21.0	8.00	11.0	32.0	9.60	9.70
Jul	1.00	7.20	378	11	0.80	4.40	0.06	2.67	0.05	25.0	23.0	32.0	37.0	10.6	1.20
Aug	0.80	7.30	506	11	0.50	2.70	0.02	3.50	0.04	37.0	45.0	31.0	39.0	12.2	2.20
Sep	0.20	7.10	601	11	0.90	4.00	0.02	3.66	0.01	53.0	57.0	44.0	41.0	11.5	2.30
Oct	0.60	7.10	630	17	0.50	3.80	0.06	3.65	0.12	43.0	82.0	51.0	41.0	13.2	2.50
Nov	0.60	7.30	505	25	1.30	4.80	0.05	3.88	0.02	47.0	81.0	50.0	44.0	12.7	2.50
Dec	1.40	7.50	527	11	0.30	3.00	0.02	3.52	0.03	39.0	68.0	53.0	43.0	12.3	2.40
1975															
Jan	1.23	7.70	484	18	0.20	2.90	0.04	3.04	0.01	44.0	68.0	48.0	43.0	12.6	1.80
Feb	0.85	7.70	448	13	0.10	3.80	0.04	3.16	0.02	44.0	66.0	46.0	41.0	12.9	1.80
Mar	0.70	7.70	445	15	0.20	8.40	0.37	2.55	0.03	39.0	63.0	49.0	47.0	12.7	1.70
Apr	0.80	7.60	448	7	0.30	3.50	0.05	2.62	0.01	41.0	62.0	49.0	42.0	13.0	1.60
May	0.52	7.90	460	11	0.30	2.50	0.04	3.16	0.01	35.0	51.0	44.0	47.0	13.9	1.90
Jun	0.76	7.30	494	10	0.70	4.20	0.06	4.34	0.01	61.0	44.0	52.0	49.0	15.0	2.30
Jul	0.25	7.30	504	27	1.30	ND	0.05	4.41	0.01	ND	55.0	55.0	46.0	13.1	2.60
Aug							(No data for any parameter)								
Sep							(No data for any parameter)								
Oct	ND	6.90	624	20	0.40	ND	0.10	2.67	0.01	92.0	101	81.0	49.0	13.8	3.60
Nov	1.26	7.40	606	20	0.50	ND	<0.01	4.60	0.03	66.0	113	75.0	48.0	15.2	2.90
Dec	0.78	7.40	516	12	0.20	ND	0.03	3.89	0.03	50.0	97.0	ND	ND	ND	ND

Appendix C, Table 1 (continued). TREATMENT PERFORMANCE SUMMARY MONTHLY AVERAGES FOR 1974 AND 1975 DRAIN TILE NUMBER 19

							Parameters in ppm									
Year/ Month	BOD_5, ppm	pH, SU	Sp cond, μmhos/cm	Color, APHA	Turb, FTU	TOC, ppm	NH_4	NO_3/NO_2-N	o-PO_4 -P	SO_4	Cl	Na	Ca	Mg	K
1974															
Jun	0.80	7.20	389	25	4.10	5.20	0.12	2.05	0.02	66.0	9.00	10.0	49.0	15.6	1.40
Jul	0.80	7.20	472	25	3.40	4.70	0.15	2.67	0.02	60.0	26.0	27.0	51.0	15.3	1.70
Aug	0.60	7.20	589	28	3.70	4.70	0.03	3.00	0.02	67.0	51.0	32.0	51.0	17.5	3.60
Sep	0.70	7.10	729	26	3.4	4.50	0.28	2.92	0.01	64.0	68.0	46.0	58.0	17.0	3.20
Oct	0.40	7.20	728	32	3.50	6.00	0.18	2.46	0.01	64.0	84.0	50.0	62.0	18.4	3.20
Nov	1.30	7.30	633	57	4.20	11.5	0.28	1.85	0.01	86.0	84.0	48.0	69.0	18.8	3.50
Dec	1.60	7.50	569	24	2.60	4.10	0.06	2.24	0.03	61.0	76.0	46.0	63.0	16.3	2.90
1975															
Jam	1.13	7.50	576	33	2.10	12.4	0.13	2.11	0.01	73.0	77.0	51.0	61.0	16.3	2.90
Feb	0.93	7.50	585	31	1.70	5.60	0.12	2.19	0.01	71.0	81.0	52.0	59.0	18.1	2.70
Mar	1.15	7.50	556	27	1.90	11.8	0.15	1.82	0.02	53.0	79.0	56.0	64.0	18.7	2.70
Apr	1.03	7.50	577	26	2.00	5.00	0.09	1.77	0.01	65.0	78.0	52.0	58.0	17.9	2.60
May	0.60	7.60	587	26	2.60	6.90	0.13	2.73	<0.01	60.0	66.0	51.0	61.0	18.4	3.10
Jun	0.96	7.20	531	24	3.10	ND	0.16	3.35	<0.01	81.0	51.0	56.0	58.0	17.5	3.30
Jul	1.89	7.20	616	34	2.80	9.80	0.32	4.33	0.01	ND	76.0	60.0	58.0	17.50	3.70
Aug	1.27	7.00	692	41	3.60	ND	1.02	4.25	0.01	74.0	94.0	74.0	67.0	18.7	4.40
Sep	1.50	7.20	655	44	3.00	ND	0.20	3.89	0.01	77.0	94.0	71.0	66.0	16.6	4.30
Oct	1.38	7.20	715	46	3.10	ND	0.22	3.12	0.01	71.0	107	82.0	63.0	17.3	4.20
Nov	0.75	7.30	682	36	2.20	ND	0.09	2.73	0.02	77.0	128	92.0	61.0	18.1	5.00
Dec	0.90	7.30	580	33	2.30	ND	0.14	2.21	0.02	65.0	108	ND	55.0	17.7	4.00

Appendix C, Table 1 (continued). TREATMENT PERFORMANCE SUMMARY MONTHLY AVERAGES FOR 1974 AND 1975 DRAIN TILES NUMBER 34

							Parameters in ppm								
Year/ Month	BOD_5, ppm	pH, SU	Sp cond, µmhos/cm	Color, APHA	Turb, FTU	TOC, ppm	NH_4	NO_3/NO_2-N	$o\text{-}PO_4$ -P	SO_4	Cl	Na	Ca	Mg	K
1974															
Jun	0.40	7.00	604	33	29.0	6.30	0.30	1.11	0.01	168	7.00	10.0	77.0	26.1	1.80
Jul	0.80	6.90	627	81	14.0	8.10	0.24	1.28	0.01	158	14.0	18.0	76.0	24.4	1.80
Aug	1.20	7.00	615	74	17.0	5.10	0.19	1.71	0.02	146	30.0	16.0	67.0	22.2	2.70
Sep	0.50	6.90	760	134	14.7	4.60	0.23	1.08	<0.01	143	45.0	26.0	74.0	23.6	2.50
Oct	0.20	6.90	763	136	18.8	10.7	0.27	0.94	<0.01	149	51.0	29.0	77.0	24.1	2.50
Nov	0.80	7.10	642	171	24.7	5.10	0.38	0.53	0.01	236	23.0	19.0	94.0	31.7	1.9
Dec	0.70	7.20	666	80	11.9	5.00	0.31	0.64	0.01	213	22.0	15.0	106	30.5	1.80
1975															
Jan	0.87	7.20	615	137	26.7	8.80	0.38	0.84	0.01	258	25.0	17.0	99.0	29.0	1.90
Feb	0.70	7.20	573	67	25.5	18.2	0.34	0.85	0.01	260	24.0	15.0	91.0	30.7	1.80
Mar	0.90	7.00	615	70	21.7	12.2	0.35	0.81	0.02	216	26.0	16.0	98.0	33.4	1.80
Apr	0.67	7.10	599	141	23.1	9.1	0.33	0.85	0.01	206	25.0	17.0	89.0	28.4	1.70
May	1.03	7.20	583	55	19.3	11.2	0.35	1.21	<0.01	162	25.0	17.0	90.0	27.6	2.20
Jun	1.33	7.10	530	53	12.6	ND	0.36	3.55	<0.01	194	25.0	28.0	76.0	21.9	2.3
Jul	1.75	7.00	552	59	11.2	11.2	0.24	2.21	<0.01	ND	45.0	41.0	64.0	19.0	2.60
Aug	1.42	6.90	568	86	15.6	ND	0.24	2.04	0.01	175	59.0	44.0	69.0	16.7	2.8
Sep	1.11	6.90	578	90	16.0	ND	0.32	1.95	0.01	157	54.0	36.0	79.0	19.4	2.70
Oct	0.80	6.90	634	188	17.3	ND	0.41	1.36	0.01	188	46.0	19.0	87.0	24.5	2.30
Nov	1.18	7.00	568	87	12.8	ND	0.18	1.32	0.02	109	89.0	49.0	60.0	18.0	3.10
Dec	1.05	6.90	577	77	12.2	ND	0.29	0.58	0.02	136	59.0	ND	74.0	20.7	1.80

Appendix C, Table 1 (continued). TREATMENT PERFORMANCE SUMMARY MONTHLY AVERAGES FOR 1974 AND 1975 DRAIN TILE NUMBER 48

Year/ Month	BOD_5, ppm	pH, SU	Sp cond, µmhos/cm	Color, APHA	Turb, FTU	TOC, ppm	Parameters in ppm								
							NH_4	NO_3/NO_2-N	$o-PO_4$ -P	SO_4	Cl	Na	Ca	Mg	K
1974															
Jun	0.20	6.50	943	13	56.7	8.20	0.76	1.68	0.01	315	8.00	10.0	114	48.8	1.90
Jul	0.70	6.70	933	104	53.6	7.30	0.70	1.21	0.01	349	8.00	11.0	121	47.3	1.80
Aug	0.40	6.60	929	114	43.8	6.40	0.59	1.93	0.01	345	19.0	12.0	111	46.9	2.80
Sep	<0.10	6.50	1018	253	55.8	7.10	0.57	1.30	0.01	340	60.0	10.0	111	47.7	2.20
Oct	ND	6.80	1027	246	42.8	8.40	0.60	1.05	<0.01	307	34.0	19.0	111	41.9	2.20
Nov	ND	6.80	763	237	35.7	6.20	0.61	1.61	<0.01	329	36.0	ND	106	37.3	2.50
Dec	0.10	6.80	786	112	34.3	5.00	0.54	0.99	0.01	375	31.0	19.0	119	36.9	2.30
1975															
Jan	0.40	6.70	691	85	18.0	11.9	0.60	1.11	0.01	317	32.0	19.0	109	33.8	2.20
Feb	0.30	6.80	682	117	39.5	10.8	0.66	1.11	0.01	318	33.0	19.0	107	39.4	2.20
Mar	0.10	6.80	662	43	40.3	14.9	0.50	0.96	0.01	254	34.0	18.0	109	43.1	2.20
Apr	0.90	6.90	646	130	32.2	5.60	0.47	0.95	<0.01	261	31.0	18.0	97.0	36.9	2.10
May	2.58	6.90	697	50	26.7	18.0	0.54	1.32	<0.01	255	30.0	19.0	102	37.2	2.60
Jun	3.09	6.70	685	71	20.4	17.0	0.60	2.53	<0.01	302	24.0	21.0	97.0	33.2	2.70
Jul	2.92	6.70	736	81	27.2	8.40	0.43	1.50	<0.01	ND	41.0	33.0	95.0	32.8	2.90
Aug	3.15	6.70	748	190	40.0	12.8	0.47	1.42	0.01	308	55.0	32.0	97.0	37.4	3.00
Sep	1.92	6.70	694	149	23.0	ND	0.56	1.30	0.01	127	45.0	28.0	106	28.7	3.00
Oct	0.51	6.80	751	333	36.2	ND	0.62	0.60	0.01	197	49.0	19.0	104	33.4	2.80
Nov	3.00	6.80	726	99	50.0	ND	0.53	0.59	0.03	279	59.0	31.0	104	34.9	3.00
Dec	2.01	6.80	615	126	30.1	ND	0.44	0.60	0.01	223	54.0	ND	94.0	32.1	2.80

Appendix C, Table 1 (continued). TREATMENT PERFORMANCE SUMMARY MONTHLY AVERAGES FOR 1974 AND 1975 DRAIN TILES NUMBER 11 AND 19

Year/	Bacterial count range, colonies/100 ml (low→high)					
	Drain tile number 11			Drain tile number 19		
Month	Total coli	Fecal coli	Fecal strep	Total coli	Fecal coli	Fecal strep
1974						
Jun	$<1.0\to2.4\times10^{2}$	$<1.0\to2.4\times10^{2}$	$<1.0\to2.5\times10^{1}$	$5.0\times10^{0}\to1.5\times10^{2}$	$<1.0\to<1.0$	$1.0\to1.0\times10^{0}$
Jul	$<1.0\to1.4\times10^{2}$	$<1.0\to<1.0$	$<1.0\to2.0\times10^{0}$	$<1.0\to3.1\times10^{1}$	$<1.0\to<1.0$	$<1.0\to3.1\times10^{1}$
Aug	$<1.0\to2.7\times10^{1}$	$<1.0\to1.0\times10^{0}$	$<1.0\to1.1\times10^{1}$	$2.0\times10^{0}\to1.8\times10^{1}$	$<1.0\to6.0\times10^{0}$	$<1.0\to5.0\times10^{1}$
Sep	$<1.0\to1.2\times10^{2}$	$<1.0\to<1.0$	$<1.0\to1.1\times10^{1}$	$<1.0\to1.8\times10^{1}$	$<1.0\to1.0\times10^{0}$	$<1.0\to<1.0$
Oct	$4.0\times10^{0}\to8.6\times10^{1}$	$<1.0\to1.0\times10^{0}$	$<1.0\to1.0\times10^{0}$	$1.2\times10^{1}\to4.6\times10^{2}$	$<1.0\to2.3\times10^{1}$	$<1.0\to5.7\times10^{1}$
Nov	$<1.0\to8.5\times10^{2}$	$<1.0\to<1.0$	$<1.0\to1.0\times10^{0}$	$1.0\times10^{0}\to1.8\times10^{3}$	$<1.0\to7.7\times10^{1}$	$<1.0\to2.5\times10^{2}$
Dec	$<1.0\to6.2\times10^{1}$	$<1.0\to6.0\times10^{0}$	$<1.0\to<1.0$	$<1.0\to3.3\times10^{1}$	$<1.0\to2.0\times10^{0}$	$<1.0\to1.0\times10^{0}$
1975						
Jan	$2.0\times10^{0}\to8.0\times10^{1}$	$<1.0\to<1.0$	$<1.0\to<1.0$	$8.0\times10^{0}\to7.4\times10^{1}$	$<1.0\to<1.0$	$<1.0\to2.0\times10^{0}$
Feb	$2.0\times10^{0}\to4.0\times10^{0}$	$<1.0\to<1.0$	$<1.0\to<1.0$	$1.4\times10^{1}\to1.5\times10^{2}$	$<1.0\to<1.0$	$<1.0\to<1.0$
Mar	$<1.0\to2.0\times10^{0}$	$<1.0\to<1.0$	$<1.0\to<1.0$	$2.0\times10^{0}\to3.6\times10^{1}$	$<1.0\to<1.0$	$<1.0\to<1.0$
Apr	$<1.0\to1.3\times10^{1}$	$<1.0\to<1.0$	$<1.0\to<1.0$	$<1.0\to4.7\times10^{1}$	$<1.0\to3.0\times10^{0}$	$<1.0\to<1.0$
May	$<1.0\to1.2\times10^{1}$	$<1.0\to<1.0$	$<1.0\to<1.0$	$<1.0\to1.3\times10^{2}$	$<1.0\to1.0\times10^{0}$	$<1.0\to2.0\times10^{0}$
Jun	$<1.0\to4.7\times10^{1}$	$<1.0\to1.1\times10^{1}$	$<1.0\to4.7\times10^{1}$	$<1.0\to5.2\times10^{1}$	$<1.0\to4.0\times10^{0}$	$<1.0\to2.4\times10^{1}$
Jul	$1.0\times10^{0}\to1.0\times10^{0}$	$1.0\times10^{0}\to1.0\times10^{0}$	$1.0\times10^{0}\to1.0\times10^{0}$	$2.0\times10^{0}\to1.2\times10^{2}$	$1.0\times10^{0}\to1.7\times10^{1}$	$1.0\times10^{0}\to1.0\times10^{1}$
Aug		No data		$2.0\times10^{1}\to6.7\times10^{1}$	$<1.0\to4.9\times10^{1}$	$<1.0\to1.5\times10^{1}$
Sep		No data		$<1.0\to1.0\times10^{0}$	$<1.0\to<1.0$	$<1.0\to6.0\times10^{0}$
Oct		No data		$<1.0\to1.9\times10^{2}$	$<1.0\to5.0\times10^{0}$	$<1.0\to6.0\times10^{0}$
Nov	$1.6\times10^{1}\to7.1\times10^{1}$	$<1.0\to3.0\times10^{0}$	$<1.0\to3.0\times10^{0}$	$1.3\times10^{1}\to6.8\times10^{1}$	$<1.0\to6.0\times10^{0}$	$<1.0\to2.0\times10^{0}$
Dec	$7.0\times10^{0}\to3.0\times10^{1}$	$<1.0\to1.0$	$<1.0\to2.0\times10^{0}$	$1.0\times10^{0}\to1.0\times10^{1}$	$<1.0\to1.0\times10^{0}$	$<1.0\to1.0\times10^{0}$

Appendix C, Table 1 (continued). TREATMENT PERFORMANCE SUMMARY MONTHLY AVERAGES FOR 1974 AND 1975 DRAIN TILES NUMBER 34 AND 48

Year/	Bacterial count range, colonies/100 ml (low→high)					
	Drain tile number 34			Drain tile number 48		
Month	Total coli	Fecal coli	Fecal strep	Total coli	Fecal coli	Fecal strep
1974						
Jun	$<1.0\rightarrow4.7\times10^{1}$	$<1.0\rightarrow1.6\times10^{0}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$
Jul	$<1.0\rightarrow1.4\times10^{2}$	$<1.0\rightarrow4.8\times10^{0}$	$<1.0\rightarrow6.4\times10^{0}$	$<1.0\rightarrow1.7\times10^{1}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow1.0\times10^{0}$
Aug	$<1.0\rightarrow6.0\times10^{0}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow4.8\times10^{1}$	$<1.0\rightarrow3.8\times10^{1}$	$<1.0\rightarrow3.2\times10^{1}$	$<1.0\rightarrow2.8\times10^{1}$
Sep	$1.0\times10^{0}\rightarrow1.1\times10^{1}$	$<1.0\rightarrow5.0\times10^{0}$	$<1.0\rightarrow5.0\times10^{0}$	$<1.0\rightarrow8.0\times10^{0}$	$<1.0\rightarrow2.0\times10^{0}$	$<1.0\rightarrow<1.0$
Oct	$<1.0\rightarrow1.7\times10^{2}$	$<1.0\rightarrow6.0\times10^{0}$	$<1.0\rightarrow8.0\times10^{0}$	$1.0\times10^{0}\rightarrow6.0\times10^{3}$	$<1.0\rightarrow3.1\times10^{2}$	$<1.0\rightarrow2.4\times10^{2}$
Nov	$<1.0\rightarrow4.0\times10^{0}$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow5.2\times10^{1}$	$6.0\times10^{0}\rightarrow6.0\times10^{2}$	$<1.0\rightarrow1.0\times10^{0}$	$1.0\times10^{0}\rightarrow8.0\times10^{0}$
Dec	$<1.0\rightarrow3.0\times10^{2}$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow3.4\times10^{1}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow1.0\times10^{0}$
1975						
Jan	$<1.0\rightarrow1.0\times10^{2}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$	$8.0\times10^{0}\rightarrow3.6\times10^{1}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow1.0\times10^{0}$
Feb	$<1.0\rightarrow3.0\times10^{1}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow3.6\times10^{1}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow1.0\times10^{0}$
Mar	$<1.0\rightarrow1.0\times10^{1}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$
Apr	$<1.0\rightarrow3.0\times10^{0}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow8.0\times10^{0}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow1.0\times10^{0}$
May	$<1.0\rightarrow1.0\times10^{2}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow1.2\times10^{1}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow2.0\times10^{1}$
Jun	$<1.0\rightarrow1.9\times10^{1}$	$<1.0\rightarrow<1.0$	$<1.0\rightarrow1.0\times10^{0}$	$2.0\times10^{0}\rightarrow1.7\times10^{1}$	$<1.0\rightarrow1.1\times10^{1}$	$<1.0\rightarrow1.5\times10^{2}$
Jul	$<1.0\rightarrow5.0\times10^{0}$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow1.5\times10^{1}$	$1.0\times10^{0}\rightarrow2.3\times10^{1}$	$1.0\times10^{0}\rightarrow4.0\times10^{0}$	$3.0\times10^{0}\rightarrow3.0\times10^{1}$
Aug	$<1.0\rightarrow2.1\times10^{2}$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow1.1\times10^{1}$	$<1.0\rightarrow3.2\times10^{1}$	$<1.0\rightarrow1.1\times10^{1}$	$<1.0\rightarrow3.5\times10^{1}$
Sep	$<1.0\rightarrow2.0\times10^{0}$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow1.0\times10^{0}$	$1.0\times10^{0}\rightarrow1.7\times10^{2}$	$<1.0\rightarrow1.1\times10^{1}$	$<1.0\rightarrow6.3\times10^{1}$
Oct	$<1.0\rightarrow1.1\times10^{1}$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow3.0\times10^{0}$	$<1.0\rightarrow1.6\times10^{1}$	$<1.0\rightarrow8.0\times10^{0}$	$<1.0\rightarrow7.0\times10^{0}$
Nov	$4.5\times10^{1}\rightarrow1.6\times10^{2}$	$2.0\times10^{0}\rightarrow3.2\times10^{1}$	$1.0\times10^{0}\rightarrow2.8\times10^{1}$	$<1.0\rightarrow1.5\times10^{1}$	$<1.0\rightarrow3.0\times10^{0}$	$<1.0\rightarrow2.7\times10^{2}$
Dec	$1.0\times10^{0}\rightarrow3.1\times10^{1}$	$<1.0\rightarrow1.0\times10^{0}$	$<1.0\rightarrow1.8\times10^{1}$	$<1.0\rightarrow1.5\times10^{1}$	$<1.0\rightarrow3.0\times10^{0}$	$<1.0\rightarrow2.7\times10^{2}$

Appendix C, Table 2. TREATMENT PERFORMANCE SUMMARY OF YEARLY AVERAGES FOR 1973 AND 1974

			Influent		Effluent from biological treatment	
Parameter	Units	Year	Average	Range	Average	Range
BOD_5	ppm	1973	174	45.00 → 440	50.8	12.0 → 144
		1974	220	80.0 → 425	63.2	10.0 → 168
DO	ppm	1973	No data		4.54	0 → 7.90
		1974	No data		2.60	0 → 8.30
Temperature	°C	1973	25.1	11.0 → 33.0	20.7	10.0 → 28.0
		1974	22.8	12.5 → 29.5	18.3	7.0 → 30.0
pH	Standard units	1973	7.5	6.3 → 12.2	7.8	7.2 → 8.2
		1974	7.4	6.6 → 10.7	7.6	6.5 → 8.3
Specific conductivity	μmhos/cm	1973	1027	610 → 2100	1087	688 → 1270
		1974	1185	719 → 2120	1180	825 → 1670
Color	APHA	1973	No data		No data	
		1974	No data		No data	
Turbidity	FTU	1973	No data		No data	
		1974	No data		No data	
TS	ppm	1973	937	755 → 1894	880	366 → 1078
		1974	1084	118 → 2724	972	524 → 1670
TVS	ppm	1973	384	268 → 966	319	132 → 534
		1974	495	54 → 1772	400	66 → 1034
SS	ppm	1973	331	20 → 1500	138	5.00 → 870
		1974	288	40.0 → 2000	186	6.00 → 430
COD	ppm	1973	535	108 → 2561	245	115 → 960
		1974	552	150 → 1991	340	125 → 736
TOC	ppm	1973	141	32.0 → 440	74.9	28.3 → 171
		1974	139	36.5 → 440	78.4	26.0 → 490
NH_4	ppm	1973	3.58	0 → 11.7	2.06	0.3 → 5.10
		1974	7.91	0.30 → 37.4	4.58	0 → 11.8
NO_3/NO_2 - N	ppm	1973	0.03	0 → 0.10	0.63	0 → 8.02
		1974	0.07	0 → 1.09	0.14	0 → 1.70
PO_4 -P	ppm	1973	1.28	0 → 5.10	1.14	0.05 → 3.04
		1974	1.83	0.10 → 10.0	1.77	0.42 → 2.77

Appendix C, Table 2 (continued). TREATMENT PERFORMANCE SUMMARY OF YEARLY AVERAGES FOR 1973 AND 1974

			East storage lagoon		West storage lagoon	
Parameter	Units	Year	Average	Range	Average	Range
BOD_5	ppm	1973	14.2	3.00 → 33.0	10.6	1.00 → 54.0
		1974	15.3	2.00 → 35.0	5.70	1.00 → 41.0
DO	ppm	1973	3.60	0.10 → 7.20	6.20	0 → 15.5
	ppm	1974	3.10	0 → 11.7	9.60	0 → 14.1
Temperature	°C	1973	4.00	0 → 11.0	15.3	0 → 28.0
		1974	10.9	0 → 27.0	10.8	0 → 27.0
pH	standard units	1973	7.7	7.5 → 8.00	7.90	7.2 → 8.4
		1974	7.7	7.4 → 8.60	8.20	7.20 → 9.80
Specific conductivity	μmhos/cm	1973	928	801 → 1147	900	520 → 1270
		1974	1026	563 → 1560	763	390 → 1330
Color	APHA	1973	No data		No data	
		1974	No data		No data	
Turbidity	FTU	1973	No data		No data	
		1974	No data		No data	
TS	ppm	1973	No data		No data	
		1974	733	367 → 1032	532	253 → 1048
TVS	ppm	1973	No data		No data	
		1974	264	13.0 → 608	213	50.0 → 696
SS	ppm	1973	No data		No data	
		1974	25	1.00 → 1276	20.0	0 → 640
COD	ppm	1973	157	107 → 204	91.0	42.0 → 176
		1974	149	84.0 → 520	63.0	24.0 → 417
TOC	ppm	1973	42.3	25.0 → 109	25.8	13.0 → 62.0
		1974	40.0	16.0 → 99.0	18.8	9.00 → 134
NH_4	ppm	1973	1.68	0.30 → 3.70	1.22	0 → 4.52
		1974	2.44	0 → 7.00	0.17	0 2.30
NO_3/NO_2 - N	ppm	1973	0.76	0.07 → 2.22	0.68	0.02 → 3.22
		1974	1.05	0.02 → 3.84	0.54	0.07 → 3.95
PO_4 - P	ppm	1973	0.75	0.10 → 1.20	0.19	0 → 0.39
		1974	1.42	0.19 → 2.39	0.13	0 → 0.58

Appendix C, Table 2 (continued). TREATMENT PERFORMANCE SUMMARY OF YEARLY AVERAGES FOR 1973 AND 1974

			Mosquito Creek		Big Black Creek	
Parameter	Units	Year	Average	Range	Average	Range
BOD_5	ppm	1973				
		1974	2.60	0.50 → 9.20	2.10	0 → 6.00
DO	ppm	1973	7.38	0.80 → 10.1	3.89	0.90 → 7.30
		1974	6.00	0.30 → 10.9	1.80	0.40 → 7.00
Temperature	°C	1973	12.1	3.50 → 20.0	12.3	4.50 → 20.0
		1974	8.90	1.00 → 15.0	9.50	2.00 → 15.0
pH	Standard units	1973	7.50	7.20 → 8.40	6.90	6.60 → 7.60
		1974	7.40	7.00 → 7.90	6.90	6.40 → 7.50
Specific conductivity	μmhos/cm	1973	493	313 → 661	587	506 → 691
		1974	623	382 → 1250	738	460 → 1080
Color	APHA	1973	No data		No data	
		1974	No data		No data	
Turbidity	FTU	1973	No data		No data	
		1974	No data		No data	
TS	ppm	1973	No data		No data	
		1974	414	68.0 → 670	717	346 → 1015
TVS	ppm	1973	No data		No data	
		1974	173	22.0 → 390	170	71.0 → 426
SS	ppm	1973	No data		No data	
		1974	12	0 → 230	36	4.00 → 200
COD	ppm	1973	19.0	2.00 → 52.0	26.0	12.0 → 49.0
		1974	36.0	2.00 → 189	26.0	8.00 → 76.0
TOC	ppm	1973	7.70	6.30 → 10.0	8.80	7.40 → 12.9
		1974	10.9	0.50 → 40.2	8.00	4.40 → 38.1
NH_4	ppm	1973	0.34	0 → 0.69	0.35	0.07 → 0.85
		1974	0.49	0 → 1.92	0.48	0.10 → 1.02
NO_3/NO_2-N	ppm	1973	0.18	0.01 → 2.82	0.30	0.01 → 2.88
		1974	1.20	0.12 → 9.85	0.97	0.01 → 3.50
PO_4 -P	ppm	1973	0.04	0 → 0.13	0.02	0 → 0.40
		1974	0.03	0 → 0.47	0.01	0 → 0.20

Appendix C, Table 2 (continued). TREATMENT PERFORMANCE SUMMARY OF YEARLY AVERAGES FOR 1973 AND 1974

Parameter	Units	Year	Influent Average	Influent Range	Effluent from biological treatment Average	Effluent from biological treatment Range
SO_4	ppm	1973	80.0	33.0 → 312	99.0	41.0 → 201
		1974	82.0	19.0 → 710	101	32.0 → 445
Cl	ppm	1973	154	64.0 → 297	155	26.0 → 249
		1974	176	77.0 → 384	177	113 → 237
Na	ppm	1973	160	55.7 → 1253	158	132 → 202
		1974	157	68.0 → 377	164	121 → 212
Ca	ppm	1973	46.2	23.2 → 120	72.6	65.2 → 84.3
		1974	73.2	31.0 → 286	71.1	48.0 → 92.0
Mg	ppm	1973	26.9	0 → 92.2	19.2	11.0 → 35.9
		1974	16.0	11.0 → 23.8	16.2	12.4 → 21.8
K	ppm	1973	11.6	4.20 → 116	13.0	9.00 → 18.9
		1974	11.6	1.00 → 88.5	12.2	7.10 → 17.9
Fe	ppm	1973	0.94	0 → 3.36	0.68	0.42 → 1.06
		1974	1.02	0.40 → 10.5	0.92	0.04 → 2.44
Zn	ppm	1973	0.64	0 → 6.83	0.35	0.12 → 0.91
		1974	0.82	0 → 15.1	0.48	0.08 → 1.67
Mn	ppm	1973	0.30	0 → 2.88	0.29	0.20 → 0.43
		1974	0.32	0.10 → 2.30	0.30	0.02 → 1.99
Total coli	colonies/100ml	1973	No data			$2.5\times10^5 \rightarrow 7.3\times10^7$
		1974	No data		No data	
Fecal coli	colonies/100ml	1973	No data			$2.0\times10^3 \rightarrow 3.6\times10^6$
		1974	No data		No data	
Fecal strep	colonies/100ml	1973	No data			$7.0\times10^1 \rightarrow 1.2\times10^4$
		1974	No data		No data	
TKN	ppm	1973	6.30	1.20 → 16.8	4.56	1.00 → 9.80
		1974	10.6	3.90 → 23.3	7.88	4.00 → 10.2
TP	ppm	1973	1.79	0 → 3.91	1.65	0.50 → 2.70
		1974	2.70	1.01 → 4.50	2.27	1.40 → 3.10

Appendix C, Table 2 (continued). TREATMENT PERFORMANCE SUMMARY OF YEARLY AVERAGES FOR 1973 AND 1974

			East storage lagoon		West storage lagoon	
Parameter	Units	Year	Average	Range	Average	Range
SO_4	ppm	1973	101	52.0 → 368	84.0	53.0 → 146
		1974	97.0	43.0 → 670	74.0	23.0 → 270
Cl	ppm	1973	189	143 → 367	133	49.0 → 230
		1974	161	92.0 → 218	103	45.0 → 135
Na	ppm	1973	151	140 → 162	124	87.1 → 166
		1974	146	130 → 161	91.2	93.0 → 121
Ca	ppm	1973	70.6	61.1 → 77.4	52.7	30.6 → 68.7
		1974	61.9	43.0 → 84.0	51.7	28.0 → 59.0
Mg	ppm	1973	13.6	10.9 → 18.9	26.3	12.4 → 73.8
		1974	15.5	14.4 → 18.6	17.4	14.3 → 19.1
K	ppm	1973	12.7	8.90 → 15.7	9.20	6.10 → 14.0
		1974	11.4	9.20 → 13.8	5.60	3.80 → 6.70
Fe	ppm	1973	1.21	0.80 → 2.00	0.82	0 → 1.90
		1974	1.04	0.60 → 1.70	0.61	0.30 → 1.40
Zn	ppm	1973	0.26	0.10 → 2.30	0.18	0.10 → 0.50
		1974	0.24	0.10 → 0.30	0.08	0 → 0.20
Mn	ppm	1973	0.20	0.10 → 0.30	0.06	0 → 0.30
		1974	0.17	0 → 0.30	0.05	0 → 0.30
Total coli	colonies/100ml	1973		$6.7\times10^4 \rightarrow 5.3\times10^6$		$2.0\times10^1 \rightarrow 3.7\times10^5$
		1974		$8.7\times10^1 \rightarrow 2.7\times10^6$		$2.0\times10^0 \rightarrow 1.4\times10^5$
Fecal coli	colonies/100ml	1973		$1.3\times10^3 \rightarrow 2.8\times10^5$		$7.0\times10^0 \rightarrow 9.3\times10^4$
		1974		$2.0\times10^1 \rightarrow 2.0\times10^5$		$<1.0\times10^0 \rightarrow 3.3\times10^4$
Fecal strep	colonies/100ml	1973		$3.4\times10^5 \rightarrow 1.3\times10^4$		$3.0\times10^0 \rightarrow 4.5\times10^3$
		1974		$3.0\times10^0 \rightarrow 3.2\times10^4$		$<1.0\times10^0 \rightarrow 1.3\times10^3$
TKN	ppm	1973	4.58	2.30 → 7.80	2.87	0.80 → 7.40
		1974	3.93	1.00 → 8.00	1.12	1.00 → 3.20
TP	ppm	1973	0.85	0.30 → 1.30	0.28	0 → 1.47
		1974	1.88	0.40 → 2.50	0.47	0 → 0.91

Appendix C, Table 2 (continued). TREATMENT PERFORMANCE SUMMARY OF YEARLY AVERAGES FOR 1973 AND 1974

			Mosquito Creek		Big Black Creek	
Parameter	Units	Year	Average	Range	Average	Range
SO_4	ppm	1973	78.0	48.0 → 100	214	118 → 295
		1974	83.0	40.0 → 238	327	148 → 708
Cl	ppm	1973	57.0	0 → 247	21.0	0 → 173
		1974	60.0	6.00 → 166	16.0	2.00 → 126
Na	ppm	1973	45.7	3.50 → 60.0	9.21	7.00 → 15.5
		1974	46.6	5.70 → 94.0	9.82	2.00 → 20.0
Ca	ppm	1973	64.4	59.7 → 67.3	92.1	41.0 → 111
		1974	60.9	48.0 → 80.0	111	22.0 → 155
Mg	ppm	1973	19.9	10.6 → 24.9	25.5	7.00 → 39.2
		1974	19.7	11.0 → 23.7	41.4	8.00 → 56.8
K	ppm	1973	2.46	1.10 → 3.30	2.21	1.00 → 2.70
		1974	3.18	1.20 → 7.70	2.24	1.00 → 5.70
Fe	ppm	1973	2.13	0.84 → 3.89	14.6	1.20 → 46.6
		1974	1.68	0.04 → 1.36	22.0	2.90 → 37.3
Zn	ppm	1973	0.11	0 → 0.23	0.18	0.04 → 0.43
		1974	0.12	0.09 → 6.21	0.22	0.07 → 1.14
Mn	ppm	1973	0.17	0.15 → 0.19	0.30	0.26 → 0.37
		1974	0.14	0 → 0.95	0.40	0.12 → 0.54
Total coli	colonies/100 ml	1973		$1.8\times10^1 \rightarrow 2.1\times10^4$		$1.0\times10^0 \rightarrow 1.3\times10^4$
		1974		$<1.0\times10^0 \rightarrow 6.0\times10^4$		$1.0\times10^0 \rightarrow 2.6\times10^4$
Fecal coli	colonies/100 ml	1973		$1.0\times10^0 \rightarrow 1.5\times10^3$		$<1.0\times10^0 \rightarrow 3.5\times10^3$
		1974		$<1.0\times10^0 \rightarrow 2.0\times10^3$		$1.0\times10^0 \rightarrow 2.2\times10^3$
Fecal strep	colonies/100 ml	1973		$5.6\times10^0 \rightarrow 5.5\times10^3$		$1.0\times10^0 \rightarrow 3.5\times10^2$
		1974		$<1.0\times10^0 \rightarrow 8.0\times10^2$		$1.0\times10^0 \rightarrow 1.6\times10^3$
TKN	ppm	1973	No data		No data	
		1974	No data		No data	
TP	ppm	1973	No data		No data	
		1974	No data		No data	

Appendix C, Table 2 (continued). TREATMENT PERFORMANCE SUMMARY OF YEARLY AVERAGES FOR 1974

		Drainpipe 11		Drain pipe 19	
Parameter	Units	Average	Range	Average	Range
BOD$_5$	ppm	0.80	0.10 → 4.00	0.90	0.20 → 1.80
DO	ppm	No data		No data	
Temperature	°C	No data		No data	
pH	Standard unit	7.30	6.70 → 7.70	7.20	7.00 → 7.70
Sp cond	μmhos/cm	491	255 → 792	587	306 → 838
Color	APHA	14.0	5.00 → 80.0	31.0	10.0 → 75.0
Turbidity	FTU	0.70	0 → 1.60	3.60	1.80 → 7.60
TS	ppm	No data		No data	
TVS	ppm	No data		No data	
SS	ppm	No data		No data	
COD	ppm	No data		No data	
TOC	ppm	4.00	1.40 → 13.0	5.80	3.60 → 44.6
NH$_4$	ppm	0.04	0 → 0.20	0.16	0 → 0.96
NO$_3$/NO$_2$	ppm	3.23	1.10 → 4.54	2.46	1.60 → 3.21
PO$_4$	ppm	0.01	0 → 0.11	0.02	0 → 0.05
SO$_4$	ppm	38.0	17.0 → 68.0	67.0	39.0 → 92.0
Cl	ppm	52.0	6.00 → 97.0	57.0	7.00 → 106
Na	ppm	27.6	3.10 → 59.9	32.5	2.70 → 56.0
Ca	ppm	35.6	30.0 → 47.0	57.0	34.0 → 73.0
Mg	ppm	11.7	8.10 → 13.7	17.1	13.1 → 21.7
K	ppm	1.79	0.60 → 3.70	2.82	1.10 → 6.10
Fe	ppm	0.03	0 → 0.26	0.58	0.14 → 1.19
Zn	ppm	0.05	0 → 0.11	0.03	0 → 0.05
Mn	ppm	0.01	0 → 0.05	0.10	0.04 → 0.18
Total coli	colonies/100 ml		$<1.0\times10^0 \rightarrow 1.2\times10^3$		$<1.0\times10^0 \rightarrow 1.8\times10^3$
Fecal coli	colonies/100 ml		$<1.0\times10^0 \rightarrow 2.4\times10^2$		$<1.0\times10^0 \rightarrow 7.1\times10^1$
Fecal strep	colonies/100 ml		$<1.0\times10^0 \rightarrow 2.5\times10^1$		$<1.0\times10^0 \rightarrow 2.5\times10^2$
TKN	ppm	No data		No data	
TP	ppm	No data		No data	

Appendix C, Table 2 (continued). TREATMENT PERFORMANCE SUMMARY OF YEARLY AVERAGES FOR 1974

		Drainpipe 34		Drain pipe 48	
Parameter	Units	Average	Range	Average	Range
BOD_5	ppm	0.70	0 → 1.30	0.30	0. → 2.60
DO	ppm	No data		No data	
Temperature	°C	No data		No data	
pH	Standard unit	7.00	6.10 → 7.50	6.70	6.40 → 7.00
Sp cond	μmhos/cm	668	426 → 830	914	697 → 1073
Color	APHA	101	15 → 250	154	10.0 → 480
Turbidity	FTU	18.6	3.80 → 43.0	46.1	14.0 → 84.0
TS	ppm	No data		No data	
TVS	ppm	No data		No data	
SS	ppm	No data		No data	
COD	ppm	No data		No data	
TOC	ppm	6.40	3.30 → 35.6	6.90	4.00 → 14.5
NH_4	ppm	0.27	0.10 → 0.49	0.62	0.39 → 0.95
NO_3/NO_2	ppm	1.04	0.38 → 2.19	1.40	0.80 → 2.06
PO_4 –P	ppm	0.01	0 → 0.09	0.01	0 → 0.02
SO_4	ppm	173	113 → 270	337	190 → 2445
Cl	ppm	27.3	5.90 → 63.1	28.0	4.00 → 45.0
Na	ppm	17.7	4.20 → 46.0	11.1	2.90 → 34.0
Ca	ppm	75.9	61.0 → 103	112	91.0 → 133
Mg	ppm	25.2	20.2 → 36.1	44.7	24.6 → 53.9
K	ppm	2.24	1.10 → 4.70	2.27	1.10 → 6.00
Fe	ppm	5.20	1.40 → 10.6	27.9	14.7 → 38.8
Zn	ppm	0.04	0.01 → 0.10	0.10	0.06 → 0.15
Mn	ppm	0.20	0.12 → 0.33	0.41	0.31 → 0.48
Total coli	colonies/100 ml	$<1.0\times10^0 \rightarrow 3.0\times10^2$		$<1.0\times10^0 \rightarrow 6.0\times10^2$	
Fecal coli	colonies/100 ml	$<1.0\times10^0 \rightarrow 4.8\times10^0$		$<1.0\times10^0 \rightarrow 2.4\times10^2$	
Fecal strep	colonies/100 ml	$<1.0\times10^0 \rightarrow 5.2\times10^1$		$<1.0\times10^0 \rightarrow 6.3\times10^1$	
TKN	ppm	No data		No data	
TP	ppm	No data		No data	

Appendix D, Table 1. WMS INDIVIDUAL PERIMETER WELLS, DEPTH AND STATUS

Well number	Depth, feet	Depth, meters	Status remarks	Date discovered
A-1	28	8.53		
A-2	38	11.6		
A-3	53	16.2		
B-3	52	15.8		
C-3	40	12.2	Always dry	
D-3	63	19.2	Always dry	
E-3	60	18.3	Always dry	
F-1	43	13.1		
F-2	53	16.2		
G-1	55	16.8		
H-3	43	13.1	Always dry	
I-2	33	10.1		
I-3	50	15.2	Always dry	
J-1	23	7.01	Always dry	
J-2	40	12.2	Always dry	
K-1	20	6.10		
L-1	13	3.96		
L-3	23	7.01		
M-1	13	3.96		
M-2	33	10.1		
M-3	59	18.0		
N-1	13	3.96		
N-2	23	7.01		
N-3	38	11.6		
O-1	13	3.96		
O-2	20	6.10		
O-3	28	8.53		
P	--	---	Test hole only	

Well number	Depth, feet	Depth, meters	Status remarks	Date discovered
Q-1	13	3.96	Lost during construction	
Q-2	24	7.32	Lost during construction	
Q-3	---	---	Lost during construction	
R-1	18	5.49		
R-2	28	8.53		
R-3	38	11.6		
S-1	13	3.96	Usually dry	
S-2	40	12.2		
S-3	60	18.3		
T-1	13	3.96		
T-2	38	11.6		
T-3	59	18.0		
U-1	13	3.96		
U-2	38	11.6	Well broke	4/17/75
U-3	68	20.7		
V-1	23	7.01		
V-3	31	9.45		
W-1	13	3.96		
W-2	18	5.49		
W-3	28	8.53		
X-1	13	3.96		
X-2	38	11.6		
X-3	58	17.7		
Y-1	13	3.96		
Y-2	23	7.01		
Y-3	36	11.0		
Z-1	13	3.96	Well pulled up	1/24/74
Z-2	23	7.01		
Z-3	36	11.0		

Appendix D, Table 2. **WMS INDIVIDUAL LAGOON SEEPAGE WELLS, DEPTH AND STATUS**

Well number	Depth, feet	Depth, meters	Status remarks	Date discovered
1-A	48	14.6		
1-B-1	23	7.01		
1-B-2	33	10.1		
1-B-3	48	14.6		
1-C-1	23	7.01		
1-C-2	33	10.1		
1-C-3	48	14.6		
2-A	53	16.2		
2-B-1	23	7.01		
2-B-2	33	10.1		
2-B-3	53	16.2		
2-C-1	23	7.01		
2-C-2	33	10.1		
2-C-3	53	16.2		
3-A	53	16.2		
3-B-1	23	7.01		
3-B-2	33	10.1		
3-B-3	53	16.2		
3-C-1	23	7.01		
3-C-2	33	10.1		
3-C-3	53	16.2		
4-A	58	17.7		
4-B-1	18	5.49		
4-B-2	33	10.1		
4-B-3	58	17.7		
4-C-1	18	5.49		
4-C-2	33	10.1	Missing	3/10/75
4-C-3	58	17.7		
5-A	53	16.2		
5-B-1	18	5.49		
5-B-2	33	10.1		
5-B-3	53	16.2		
5-C-1	18	5.49		
5-C-2	38	11.6		
5-C-3	63	19.2		
6-A	60	18.3		
6-B-1	18	5.49		
6-B-2	28	8.53		
6-B-3	41	12.5		
6-C-1	13	3.96		
6-C-2	23	7.01		
6-C-3	31	9.45		
7-A	55	16.8		
7-B-1	13	3.96		
7-B-2	28	8.53		
7-B-3	43	13.1		
7-C-1	13	3.96		
7-C-2	24	7.32		
7-C-3	-	-	Missing	5/20/74
8-A	43	13.1		
8-B-1	13	3.96		
8-B-2	33	10.1		
8-B-3	48	14.6		
8-C-1	13	3.96		
8-C-2	28	8.53		
8-C-3	43	13.1		
9-A	53	16.2		
9-B-1	13	3.96		

Appendix D, Table 2 (continued). WMS INDIVIDUAL LAGOON SEEPAGE WELLS, DEPTH AND STATUS

Well number	Depth, feet	Depth, meters	Status remarks	Date discovered
9-B-2	28	8.53		
9-B-3	48	14.6		
9-C-1	13	3.96		
9-C-2	43	13.1		
9-C-3	63	19.2	Destroyed in brush fire	7/7/75
10-A	50	15.2		
10-B-1	13	3.96		
10-B-2	28	8.53		
10-B-3	43	13.1		
10-C-1	13	3.96	Destroyed in brush fire	7/14/75
10-C-2	33	10.1	Destroyed in brush fire	7/14/75
10-C-3	63	19.2	Destroyed in brush fire	7/14/75
11-A	48	14.6		
11-B-1	13	3.96		
11-B-2	23	7.01		
11-B-3	33	10.1		
11-C-1	13	3.96		
11-C-2	38	11.6		
11-C-3	68	20.7		
12-A	50	15.2		
12-B-1	13	3.96		
12-B-2	33	10.1		
12-B-3	48	14.6		
12-C-1	13	3.96		
12-C-2	38	11.6		
12-C-3	68	20.7	Well broke	8/14/75
12A-C-1	13	3.96		
12A-C-2	38	11.6		
12A-C-3	68	20.7		
13-A	53	16.2		
13-B-1	13	3.96		
13-B-2	33	10.1		
13-B-3	51	15.5		
13-C-1	13	3.96		
13-C-2	38	11.6		
13-C-3	63	19.2		
13A-C-1	13	3.96		
13A-C-2	38	11.6		
13A-C-3	68	20.7		
14-A	43	13.1		
14-B-1	13	3.96		
14-B-2	28	8.53		
14-B-3	43	13.1		
14-C-1	18	5.49		
14-C-2	38	11.6		
14-C-3	63	19.2		
15-A	41	12.5		
15-B-1	13	3.96		
15-B-2	28	8.53		
15-B-3	40	12.2		
15-C-1	15	4.57		
15-C-2	33	10.1		
15-C-3	53	16.2		
16-A	48	14.6		
16-B-1	13	3.96		
16-B-2	23	7.01		
16-B-3	33	10.1		
16-C-1	13	3.96		

Appendix D, Table 2 (continued). WMS INDIVIDUAL LAGOON SEEPAGE WELLS, DEPTH AND STATUS

Well number	Depth, feet	Depth, meters	Status remarks	Date discovered
16-C-2	33	10.1		
16-C-3	48	14.6		
17-A	40	12.2		
17-B-1	13	3.96		
17-B-2	28	8.53		
17-B-3	43	13.1		
17-C-1	13	3.96		
17-C-2	33	10.1		
17-C-3	48	14.6		
18-A	38	11.6		
18-B-1	13	3.96		
18-B-2	28	8.53		
18-B-3	43	13.1		
18-C-1	13	3.96		
18-C-2	33	10.1		
18-C-3	63	19.2		
19-A	41	12.5		
19-B-1	13	3.96		
19-B-2	28	8.53		
19-B-3	43	13.1		
19-C-1	13	3.96	Well broke	4/9/74
19-C-2	33	10.1		
19-C-3	48	14.6		
20-A	43	13.1		
20-B-1	13	3.96		
20-B-2	23	7.01		
20-B-3	38	11.6		
20-C-1	13	3.96		
20-C-2	28	8.53		
20-C-3	43	13.1		
21-A	48	14.6		
21-B-1	13	3.96		
21-B-2	28	8.53		
21-B-3	43	13.1		
21-C-1	13	3.96		
21-C-2	23	7.01		
21-C-3	48	14.6		
22-A	43	13.1		
22-B-1	13	3.96		
22-B-2	28	8.53		
22-B-3	43	13.1		
22-C-1	13	3.96		
22-C-2	43	13.1	Well broke	1/22/74
22-C-3	73	22.3		
23-A	46	14.0	Well broke	11/18/74
23-B-1	13	3.96		
23-B-2	28	8.53		
23-B-3	38	11.6		
23-C-1	13	3.96		
23-C-2	28	8.53		
23-C-3	43	13.1		
24-A	38	11.6		
24-B-1	13	3.96		
24-B-3	18	5.49		
24-C-1	13	3.96		
24-C-2	28	8.53		
24-C-3	43	13.1		
25-A	58	17.7		

Appendix D, Table 2 (continued). WMS INDIVIDUAL LAGOON SEEPAGE WELLS, DEPTH AND STATUS

Well number	Depth, feet	Depth, meters	Status remarks	Date discovered
25-B-1	13	3.96		
25-B-2	28	8.53		
25-B-3	43	13.1		
25-C-1	13	3.96		
25-C-2	33	10.1		
25-C-3	55	16.8	Well broke	7/21/75
26-A	83	25.3		
26-B-1	13	3.96		
26-B-2	23	7.01		
26-B-3	35	10.7		
26-C-1	13	3.96		
26-C-2	38	11.6		
26-C-3	63	19.2		
27-A	65	19.8	See footnote	
27-B-1	13	3.96	See footnote	
27-B-2	43	13.1	See footnote	
27-B-3	78	23.8	See footnote	
27-C-1	13	3.96		
27-C-2	43	13.1	Usually dry	
27-C-3	65	19.8	Usually dry	
28-A	73	22.3	See footnote	
28-B-1	13	3.96	See footnote	
28-B-2	43	13.1	See footnote	
28-B-3	68	20.7	See footnote	
28-C-1	13	3.96		
28-C-2	43	13.1		
28-C-3	73	22.3		
29-A	68	20.7	See footnote	
29-B-1	13	3.96	See footnote	
29-B-2	38	11.6	See footnote	
29-B-3	68	20.7	See footnote	
29-C-1	13	3.96		
29-C-2	38	11.6		
29-C-3	63	19.2		
30-A	63	19.2		
30-B-1	13	3.96		
30-B-2	21	6.40		
30-B-3	30	9.14		
30-C-1	13	3.96		
30-C-2	32	9.75		
30-C-3	53	16.2		
31-A	43	13.1		
31-B-1	23	7.01	Well broke	12/12/75
31-B-2	33	10.1		
31-B-3	43	13.1		
31-C-1	23	7.01		
31-C-2	33	10.1		
31-C-3	48	14.6		
32-A	43	13.1		
33-A	43	13.1		
33-B-1	23	7.01		
33-B-2	33	10.1		
33-B-3	48	14.6		
33-C-1	23	7.01		
33-C-2	33	10.1		
33-C-3	48	14.6		
34-C-1	13	3.96		
34-C-2	38	11.6		
34-C-3	68	20.7		

Footnote: Lost during construction of solid waste facility

APPENDIX E

MODEL FOR CALCULATION OF STORAGE LAGOON EVAPORATION[6]

Equation: $E = 0.013\,F\,(T_{avg} - 32)$ where:

E = evaporation in inches (daily)
F = seasonal atmospheric constant
T_{avg} = average daily temperature (°F)

Appendix E, Table 1. TABLE OF ATMOSPHERIC CONSTANTS, AVERAGE DAILY TEMPERATURES AND MONTHLY LAGOON EVAPORATION

Month	Atmospheric constant, (F)	Average daily Temperature °F, (T_{avg})	Number of days	Total evaporation, inches
January	0.101	24.1	31	–
February	0.101	25.1	28	–
March	0.200	32.5	31	0.040
April	0.200	45.3	30	1.037
May	0.298	55.7	31	2.846
June	0.298	65.6	30	3.905
July	0.294	70.2	31	4.526
August	0.294	68.9	31	4.372
September	0.194	61.5	30	2.232
October	0.194	51.5	31	1.525
November	0.124	39.3	30	0.353
December	0.124	28.8	31	–
			Total annual evaporation, inches =	20.836

Typical calculation (June):

$$E,\ \text{inches} = (0.013)\,(0.298)\,[\,(65.6 - 32)\,]\,(30)$$
$$= 3.905$$

Volume calculation:

20.836 inches x (feet/12 inches) x 1700 acres x (1.233 TCM/acre-feet) = 3642 TCM

Appendix F, Table 1. 1972 CORN TRIAL DATA

Plot number	Variety	Company	Maturity, days	Date planted
1 A & B	200	GLH	82	5/30/72
2 A & B	202 LR	Teweles	82	5/30/72
3 A & B	TXT 53	Teweles	83	5/30/72
4 A & B	G 5150	Funks	87	5/30/72
5 A & B	280	GLH	87	5/30/72
6 A & B	275 2X	GLH	87	5/30/72
7 A & B	3937	Pioneer	88	5/30/72
8 A & B	G 4180	Funks	92	5/30/72
9 A & B	3909	Pioneer	97	6/01/72
10 A & B	3911	Pioneer	92	6/01/72
11 A & B	3956 A	Pioneer	89	6/01/72
12 A & B	PX 20	NK	92	6/01/72
13 A & B	PX 446	NK	92	6/01/72
14 A & B	XL 12	DeKalb	92	6/01/72
15 A & B	TXS 94	Trojan	94	6/01/74
16 A & B	263	Teweles	93	6/01/72
17 A & B	396 3X	GLH	97	6/01/72
18 A & B	410 2X	GLH	97	6/01/72
19 A & B	G 4252	Funks	97	6/01/72
20 A & B	G 4263	Funks	92	6/01/72
21 A & B	XL 306	DeKalb	97	6/01/72
22 A & B	XL 325	DeKalb	107	6/01/72
23 A & B	CB 55	Cowbell	98	6/01/72
24 A & B	SX 102	Cowbell	100	6/01/72
25 A & B	CB 145 B	Cowbell	98	6/01/72
26 A & B	TX 99	Trojan	99	6/01/72
27 A & B	SXT 16	Teweles	102	6/01/72
28 A & B	G 4343	Funks	100	6/01/72
29 A & B	3853	Pioneer	90	6/01/72
30 A & B	TX 100	Trojan	100	6/01/72
31 A & B	TXT 61	Teweles	103	6/01/72
32 A & B	TXT 61 A	Teweles	103	6/01/72
33 A & B	G 4444	Funks	107	6/01/72
34 A & B	TXS 102	Trojan	102	6/01/72
35 A & B	TX 102	Trojan	102	6/01/72
36 A & B	TXS 103	Trojan	103	6/01/72
37 A & B	TXS 104	Trojan	104	6/01/72
38 A & B	500-2X	GLH	107	6/01/72
39 A & B	3773	Pioneer	107	6/01/72
40 A & B	SX 33	PAG	105	6/01/72
41 A & B	TXT 80	Teweles	108	6/01/72
42 A & B	SXT 21	Teweles	107	6/01/72
43 A & B	SXT 24	Teweles	109	6/01/72

Appendix F, Table 2. 1972 CLIMATE DATA DURING CORN CROP YEAR

Month/day		Rainfall, cm	Temperature, °C High	Low	GDD
May	31[a]	0.03	14	4	4.0
June	1	0	19	4	8.0
	2	0.74	24	9	13.0
	3	0.03	25	15	18.0
	4	0	28	13	19.0
	5	Trace	26	9	14.5
	6	Trace	28	14	19.5
	7	0	24	8	13.0
	8	0	24	11	14.0
	9	0	23	8	11.5
	10	0	17	4	6.0
	11[b]	0	20	-1	9.0
	12	1.4	19	11	9.0
	13	0.03	27	15	20.0
	14	4.0	28	14	20.5
	15	0.58	22	12	12.5
	16	0	17	10	6.5
	17	0	20	7	9.0
	18	0	26	8	14.0
	19	0	31	13	20.5
	20	0.56	22	8	10.5
	21	0	18	8	7.0
	22	0.10	20	9	9.0
	23	0.23	17	8	6.5
	24	Trace	17	8	6.0
	25	0	23	8	12.0
	26	0	24	9	13.0
	27	0	25	9	13.5
	28	0.10	29	12	19.5
	29	2.6	24	17	19.0
	30	0	24	16	18.0
July	1	0.81	26	11	15.5
	2	0	24	16	17.5
	3	0	19	11	8.5
	4	0	18	9	7.5
	5	0	22	8	10.5
	6	0	22	7	11.0
	7	0.66	23	13	15.0
	8	0	20	11	10.0
	9	0	24	14	16.5
	10	Trace	27	14	18.5
	11	0	30	19	26.5
	12	0.18	28	20	25.5
	13	0	21	17	16.5
	14	3.5	28	16	21.5
	15	0	24	16	17.5
	16	0	27	14	18.5
	17	1.9	29	16	22.5
	18	Trace	23	18	19.5
	19	0	29	17	23.5
	20	0	31	21	28.0
	21	0	31	21	28.0
	22	0	31	24	30.5
	23	0	28	21	26.0
	24	0	28	17	23.0
	25	0	24	15	17.0
	26	1.2	16	11	6.0
	27	0	24	13	15.5
	28	0	24	12	15.0
	29	0	26	12	16.5
	30	0	26	12	16.0
	31	0	26	13	17.5

[a] Planting date
[b] Day with freezing temperature

Appendix F, Table 2 (continued). 1972 CLIMATE DATA DURING CORN CROP YEAR

Month/day		Rainfall, cm	Temperature, °C High	Temperature, °C Low	GDD
August	1	1.7	26	17	20.0
	2	0.53	24	16	18.0
	3	0	27	3	15.0
	4	0	23	4	12.0
	5	0.03	23	12	14.0
	6	0.86	19	14	12.5
	7	0.13	17	8	6.0
	8	0.13	18	10	7.0
	9	0	21	4	10.0
	10	0.28	22	11	12.0
	11	0.51	19	14	12.0
	12	0	27	15	20.0
	13	0	29	12	19.0
	14	0	29	12	19.0
	15	0	26	11	15.0
	16	4.80	22	17	17.0
	17	0.41	29	19	25.0
	18	1.60	29	19	25.5
	19	0	29	14	20.5
	20	0	30	18	25.0
	21	0.03	31	20	27.0
	22	0	30	17	24.5
	23	1.10	27	17	21.5
	24	0	23	12	13.5
	25	6.60	29	18	24.0
	26	0.05	23	17	17.5
	27	0	27	10	15.0
	28	0	27	11	16.0
	29	0	27	13	18.0
	30	0	31	16	23.0
	31	0	29	16	22.0

Month/day		Rainfall, cm	Temperature, °C High	Temperature, °C Low	GDD
September	1	0	26	16	19.0
	2	0.03	27	4	15.0
	3	0	20	8	9.0
	4	0	22	4	11.0
	5	0	22	13	14.0
	6	0	27	17	21.0
	7	0.76	21	17	16.0
	8	0	23	12	13.0
	9	0	22	7	10.5
	10	0	23	3	12.0
	11	Trace	19	16	13.0
	12	3.3	21	16	15.0
	13	0	23	13	15.0
	14	0	23	4	12.0
	15	0	22	8	11.0
	16	0	24	11	14.0
	17	2.3	29	11	18.0
	18	0	27	13	18.0
	19	0	21	13	13.0
	20	Trace	26	14	18.0
	21	0.07	20	0	9.0
	22	0	20	1	9.0
	23	0	16	5	5.5
	24	0.05	22	7	11.0
	25	0.10	22	16	16.0
	26	0	22	4	11.0
	27		18	13	10.0
	28	1.50	22	10	11.0
	29	0	17	8	6.5
	30	0	12	6	1.5

Appendix F, Table 2 (continued). 1972 CLIMATE DATA DURING CORN CROP YEAR

Month/day		Rainfall, cm	Temperature, °C		GDD
			High	Low	
October	1	0.13	17	1	6.0
	2	0	23	7	12.0
	3	0	22	15	15.5
	4	0	23	12	14.0
	5	0.38	18	10	7.0
	6	0	16	7	5.5
	7	0	14	2	3.5
	8[c]	0	16	-4	5.0
	9	0	14	-2	4.0
	10	0	15	1	5.5
	11	0.10	17	8	6.0
	12	0.10	10	-2	0
	13	0	14	5	4.0
	14	0	16	6	5.0
	15	0.51	16	-4	5.0
	16	Trace	16	-1	5.0
	17	Trace	6	-6	0
	18	0.53	3	-9	0
	19	0	7	-4	0
	20	0	10	0	0
	21	2.2	10	4	0
	22	4.2	10	0	0
	23	0.23	12	1	2.0
	24	0.07	4	-1	0
	25	0	9	1	0
	26	0	13	8	2.5
	27	0.30	13	3	2.5
	28	0.20	12	6	2.0
	29	0	9	1	0
	30	0	13	-2	3.0
	31	0.38	6	2	0

[c] Killing freeze

Month/day		Rainfall, cm	Temperature, °C		GDD
			High	Low	
November	1	0.18	9	5	0
	2	0.71	13	7	3.0
	3	0.10	9	5	0
	4	0.03	7	4	0
	5	0	9	4	0
	6	0.03	15	2	4.5
	7	0.86	12	9	1.5
	8	0.05	10	4	0
	9	0	6	4	0
	10	Trace	7	4	0
	11	0	9	4	0
	12	0	8	1	0
	13	0.10	4	-1	0
	14	0.13	3	-3	0
	15	0	3	-2	0
	16	0	2	-4	0
	17	Trace	3	-6	0
	18	Trace	3	1	0
	19	0	4	1	0
	20	Trace	6	-1	0
	21[d]	0.21	3	0	0

[d] Harvest

Appendix F, Table 3. FIELD CORN PLANT POPULATION

Plot number	Emergence, plants/ha	Mid Growing Season, plants/ha	Harvest, plants/ha
1 A	31,400	32,400	32,100
2 A	34,400	31,400	32,900
3 A	38,100	34,600	31,600
4 A	39,300	40,800	30,900
5 A	39,500	36,100	34,100
6 A	35,800	34,600	32,900
7 A	37,300	37,300	35,600
8 A	37,100	36,300	34,300
9 A	49,700	49,200	39,500
10 A	39,800	36,100	29,400
11 A	57,800	52,100	41,800
12 A	43,500	42,700	35,300
13 A	41,500	43,000	34,600
14 A	44,200	41,800	34,300
15 A	54,800	49,200	37,300
16 A	42,000	42,300	31,900
17 A	40,000	34,600	30,600
18 A	37,600	38,500	27,700
19 A	43,200	43,700	35,600
20 A	38,800	38,800	38,300
21 A	40,000	35,300	31,600
22 A	40,000	39,500	37,100
23 A	37,800	37,300	36,900
24 A	37,100	36,800	35,600
25 A	39,000	37,100	36,800
26 A	35,100	35,300	34,600
27 A	35,300	35,100	34,800
28 A	38,300	38,300	38,300
29 A	38,800	36,100	34,100
30 A	37,600	36,100	36,800
31 A	35,600	34,600	34,300
32 A	39,500	39,500	39,000
33 A	38,500	38,500	38,300
34 A	35,800	34,300	33,400
35 A	34,800	33,100	31,900
36 A	34,800	36,000	31,600
37 A	39,500	37,100	36,500
38 A	36,900	34,100	32,100
39 A	35,800	34,100	31,600
40 A	28,700	33,100	30,400
41 A	29,400	33,100	30,400
42 A	31,900	35,300	-
43 A	33,100	44,200	-

Appendix F, Table 3 (continued). FIELD CORN PLANT POPULATION

Plot number	Emergence, plants/ha	Mid Growing Season, plants/ha	Harvest, plants/ha
1 B	29,900	33,400	32,600
2 B	26,400	27,200	28,400
3 B	34,800	33,400	31,600
4 B	39,000	37,100	33,800
5 B	38,300	37,100	37,300
6 B	36,600	34,600	32,900
7 B	34,100	33,600	33,600
8 B	30,900	30,900	30,100
9 B	46,500	40,800	40,500
10 B	34,600	31,600	30,600
11 B	51,100	45,200	39,600
12 B	39,000	37,800	34,300
13 B	37,300	31,600	31,600
14 B	36,000	36,100	29,400
15 B	51,900	44,700	36,600
16 B	36,600	33,600	32,900
17 B	30,400	30,400	32,300
18 B	30,400	29,700	31,400
19 B	32,900	28,900	30,600
20 B	36,300	36,600	33,400
21 B	33,900	29,700	29,700
22 B	37,800	37,600	30,100
23 B	32,900	33,100	27,700
24 B	30,600	28,700	28,700
25 B	31,100	28,700	26,200
26 B	29,900	29,700	25,000
27 B	34,100	27,800	27,700
28 B	32,100	27,800	30,400
29 B	31,400	33,100	28,900
30 B	31,400	35,300	29,200
31 B	30,600	30,600	30,100
32 B	33,100	30,600	30,600
33 B	36,500	34,600	33,600
34 B	27,200	30,600	30,600
35 B	28,400	29,900	31,100
36 B	33,400	32,400	33,600
37 B	38,300	35,800	35,100
38 B	31,100	29,700	28,900
39 B	31,600	31,400	30,900
40 B	27,200	29,700	29,700
41 B	28,200	31,600	28,200
42 B	25,900	32,100	-
43 B	32,600	35,200	-

Appendix F, Table 4. 1972 CORN YIELD CHECK REPORT

Plot number	Population, plants/ha	Moisture content, percent	Metric tons/ha	Plot number	Population, plants/ha	Moisture content, percent	Metric tons/ha
1 A	32,100	37.0	3.21	1 B	32,600	31.2	3.18
2 A	32,900	33.0	4.25	2 B	28,400	27.0	4.16
3 A	31,600	31.0	4.81	3 B	31,600	26.0	4.63
4 A	30,900	32.5	4.11	4 B	33,900	29.6	4.67
5 A	34,100	34.0	4.15	5 B	37,100	33.0	4.12
6 A	32,900	39.0	3.21	6 B	32,900	34.2	3.41
7 A	35,600	38.0	3.53	7 B	33,600	33.0	3.99
8 A	34,300	33.4	4.13	8 B	30,100	31.0	4.49
9 A	39,500	28.5	4.87	9 B	40,500	28.4	4.72
10 A	29,400	35.0	3.98	10 B	30,600	35.5	3.99
11 A	41,800	31.0	4.31	11 B	33,600	32.0	4.31
12 A	35,300	32.6	4.03	12 B	34,300	31.8	4.58
13 A	34,600	30.0	3.00	13 B	31,600	32.0	3.45
14 A	34,300	32.0	3.86	14 B	29,400	31.0	3.93
15 A	37,300	34.0	4.58	15 B	36,600	34.8	5.27
16 A	31,900	30.5	4.33	16 B	32,900	32.5	4.41
17 A	30,600	40.+	3.24	17 B	32,400	40.0	3.58
18 A	28,700	40.+	3.74	18 B	31,400	40.0	3.94
19 A	35,600	32.5	4.84	19 B	30,600	34.0	3.72
20 A	38,300	29.5	4.37	20 B	33,400	31.6	4.34
21 A	31,600	31.5	3.87	21 B	29,700	31.5	4.08
22 A	37,100	35.5	3.58	22 B	30,100	33.0	3.84
23 A	36,800	39.0	3.56	23 B	27,700	38.0	3.79
24 A	35,600	31.2	3.96	24 B	28,700	32.0	4.35
25 A	36,800	30.2	3.61	25 B	26,200	33.2	4.11
26 A	34,600	30.0	3.47	26 B	25,000	31.5	3.51
27 A	34,800	32.5	3.75	27 B	27,700	32.8	3.60
28 A	38,300	37.0	4.10	28 B	30,400	40.+	3.75
29 A	34,100	28.0	3.44	29 B	28,900	30.5	4.33
30 A	36,800	33.8	4.18	30 B	29,200	34.2	4.14
31 A	34,300	35.4	4.11	31 B	30,100	35.0	3.93
32 A	39,000	34.8	4.19	32 B	30,600	35.2	3.71
33 A	38,300	40.+	4.11	33 B	33,600	40.+	4.08
34 A	33,400	40.+	3.86	34 B	30,100	40.+	3.50
35 A	31,900	40.+	4.00	35 B	31,100	40.+	3.09
36 A	31,600	33.2	4.53	36 B	33,600	31.0	3.78
37 A	36,600	40.+	3.30	37 B	35,100	40.+	3.97
38 A	32,100	40.+	3.96	38 B	28,900	40.+	3.20
39 A	31,600	40.+	3.27	39 B	30,900	40.+	2.93
40 A	30,400	40.+	3.48	40 B	38,300	40.+	3.45
41 A	30,400	40.+	3.69	41 B	34,800	40.+	3.42

Appendix F, Table 5. 1973 FIELD CORN TEST PLOTS

Plot number	Variety	Company	Maturity, days	Date planted
1	7300	Cowbell	108	5/29/73
2	47	NK	108	5/29/73
3	556	NK	108	5/29/73
4	545	NK	108	5/29/73
5	3773	Pioneer	108	5/30/73
6	G 4444	Funks	108	5/30/73
7	W 240	National	108	5/30/73
8	W 255	National	108	5/30/73
9	G 4343	Funks	103	5/30/73
10	61 A	Teweles	103	5/30/73
11	3786	Pioneer	103	5/30/73
12	102	Trojan	103	5/30/73
13	1901	Acco	98	5/30/73
14	2901	Acco	103	5/30/73
15	2301	Acco	103	5/30/73
16	30	NK	103	5/30/73
17	519	NK	103	5/30/73
18	G 4366	Funks	103	5/30/73
19	SX 53	PAG	98	5/30/73
20	G 4252	Funks	98	5/30/73
21	3956 A	Pioneer	93	5/30/73
22	3956 A	Pioneer	93	5/30/73
23	476	NK	98	5/30/73
24	3797	Pioneer	98	5/30/73
25	122 A	Jacques	98	5/31/73
26	162 A	Jacques	98	5/31/73
27	100	Trojan	98	5/31/73
28	3909	Pioneer	93	5/31/73
29	3853	Pioneer	93	5/31/73
30	3956 A	Pioneer	93	5/31/73
31	448	NK	93	5/31/73
32	446	NK	93	5/31/73
33	90	Trojan	93	5/31/73
34	94	Trojan	93	5/31/73
35	92	Trojan	93	5/31/73

Appendix F, Table 5 (continued). 1973 FIELD CORN TEST PLOTS

Plot number	Variety	Company	Maturity, days	Date planted
36	62	Jacques	93	5/31/73
37	962	Jacques	93	5/31/73
38	52	Jacques	93	5/31/73
39	67	PAG	93	5/31/73
40	002	Cowbell	88	5/31/73
41	G 5150	Funks	88	5/31/73
42	JX 902	Jacques	88	5/31/73
43	G 4082	Funks	88	5/31/73
44	G 4195	Funks	88	5/31/73
45	8359	Pioneer	88	5/31/73
46	521	NK	88	5/31/73
47	3959	Pioneer	88	5/31/73
48	85	Trojan	88	5/31/73
49	53	Teweles	83	5/31/73

Appendix F, Table 6. 1973 HARVEST SUMMARY OF CORN PLOTS

Plot number	Population, plants/ha	Moisture content, percent	Metric tons/ha
1	42,000	26.5	6.77
2	53,600	27.2	6.84
3	55,100	28.0	7.51
4	58,600	26.5	7.19
5	61,800	26.0	7.17
6	58,600	26.5	6.87
7	55,100	32.5	7.33
8	53,000	38.0	6.32
9	58,600	23.0	7.27
10	60,000	22.0	6.52
11	58,600	21.5	7.54
12	58,600	24.5	8.29
13	61,000	21.0	6.42
14	56,800	23.0	7.36
15	64,200	21.8	8.37
16	59,300	22.0	7.68
17	53,600	21.5	7.32
18	57,600	24.4	7.56
19	56,800	26.5	8.13
20	66,700	20.6	7.16
21	59,300	21.0	6.76
22	59,300	20.7	6.70
23	55,100	20.0	5.84
24	60,000	21.0	7.27
25	57,600	24.0	7.54
26	63,500	23.8	7.37
27	61,000	23.0	6.71
28	60,000	20.0	7.05
29	59,300	19.8	5.96
30	60,000	20.2	5.46
31	59,300	19.5	5.02
32	63,500	18.0	4.66
33	61,800	20.0	4.82
34	66,000	20.0	6.20
35	61,000	21.2	6.03
36	62,500	21.0	6.22
37	60,000	22.9	5.73
38	61,800	22.0	6.15
39	60,000	29.0	6.47
40	55,100	20.5	5.89
41	66,000	19.5	4.53
42	57,600	19.7	5.04
43	66,700	17.5	4.53
44	56,100	20.0	5.48
45	60,000	19.6	7.23
46	53,600	22.0	6.01
47	61,000	19.0	6.14
48	60,000	19.0	5.69
49	61,000	18.2	5.09

Appendix F, Table 7. EFFLUENT AND SOIL ANALYSIS FOR 1974 GROWTH BOX STUDY

Parameter	ppm	kg/ha/yr[a] at 6.4 cm/wk	kg/ha/yr[a] at 10.2 cm/wk
Effluent analysis			
NO_3-N	1.75	34	54
PO_4	4.6	87	140
K	8	152	244
SO_4	85	1620	2590
Na	140	2667	4267
Ca	35	667	1062
Mg	40	761	1219
Comparable fertilizer nutrients			
N		34	54
P_2O_5		131	211
K_2O		183	294

[a] One year = 30 weeks of effluent irrigation

Soil analysis[b]	
N = 6 kg/ha	N = 6 kg/ha
P = 29 kg/ha	P_2O_5 = 67 kg/ha
K = 120 kg/ha	K_2O = 143 kg/ha

[b] Soil analysis performed on 'A' horizon soil only, 0 to 15 cm depth

Appendix F, Table 8. WEEKLY EFFLUENT ANALYSIS

Week	ppm												pH	Conductivity, μmhos/cm^2
	Ca	Mg	Na	K	Zn	Cr	Pb	NH_4-N	NO_3-N	PO_4	SO_4	Cl		
12/10 - 12/13	73.8	11.6	148	28.5	0.59	0.07	<0.25	0.87	3.64	4.02	-	179	7.4	966
12/14 - 1/03	70.5	12.6	153	13.8	1.50	<0.05	<0.25	1.03	0.48	3.47	106	191	7.1	1031
1/04 - 1/10	65.2	14.8	138	10.4	1.21	<0.07	<0.25	0.54	0.03	3.14	79	207	7.0	1001
1/11 - 1/17	67.7	16.7	133	11.4	0.98	<0.06	<0.25	0.42	0.05	3.52	73	206	6.9	990
1/18 - 1/24	68.7	16.9	155	13.0	1.14	<0.06	<0.25	0.39	0.05	3.55	-	237	6.5	1121
1/25 - 1/31	68.2	16.9	166	13.7	1.28	0.11	<0.26	0.35	0.04	3.27	110	229	6.8	1128
2/01 - 2/07	71.8	16.3	173	15.3	0.94	<0.08	<0.28	0.66	0.04	3.96	98	256	6.9	1213
2/08 - 2/14	73.4	16.0	159	13.0	0.89	0.10	<0.27	0.46	0.03	3.22	102	259	6.6	1135
2/15 - 2/21	74.8	16.5	161	13.1	0.45	<0.07	<0.27	0.28	0.03	3.28	88	246	6.6	1148
2/22 - 2/28	68.8	16.2	152	12.3	1.68	<0.08	<0.26	0.34	0.25	2.54	85	259	6.3	1129
3/01 - 3/07	67.3	14.9	144	13.5	0.86	<0.06	<0.25	0.55	0.04	3.28	55	223	6.7	1098
Average	70.0	15.4	153	14.4	1.05	<0.07	<0.26	0.54	0.43	3.39	88	227	6.8	1087

Appendix F, Table 9. SELECTED PARAMETERS APPLIED IN EFFLUENT

[Upper values at 6.4 cm application. Lower values *(italics)* at 10.2 cm application]
(kilograms/hectare)

Days applied 1973-1974	Ca	Mg	Na	K	Zn	Cr	Pb	NH_4-N	NO_3-N	SO_4	PO_4	Cl
12/10-12/13	37.4 *59.0*	5.8 *9.3*	74.9 *119.8*	14.5 *23.1*	0.30 *0.48*	0.03 *0.06*	0.02 *0.03*	0.44 *0.69*	1.85 *2.96*	44.7 *71.5*	2.04 *3.26*	91.0 *145.6*
12/14- 1/03	71.6 *114.6*	12.8 *20.4*	155.6 *248.9*	14.0 *22.4*	1.52 *2.44*	0.03 *0.06*	0.18 *0.29*	1.05 *1.68*	0.48 *0.77*	108.1 *172.9*	3.52 *5.63*	194.5 *311.3*
1/04- 1/10	41.4 *66.1*	9.4 *15.0*	87.3 *139.7*	6.6 *10.5*	0.77 *1.23*	0.03 *0.06*	0.03 *0.06*	0.34 *0.54*	0.02 *0.03*	50.0 *80.0*	2.00 *3.19*	131.8 *210.9*
1/11- 1/17	42.9 *68.7*	10.6 *17.0*	84.2 *134.7*	7.2 *11.4*	0.62 *0.99*	0.03 *0.06*	0.08 *0.12*	0.27 *0.43*	0.03 *0.06*	55.7 *89.2*	2.24 *3.59*	130.7 *209.2*
1/18- 1/24	43.3 *69.7*	10.8 *17.3*	98.4 *157.5*	8.3 *13.2*	0.73 *1.17*	0.03 *0.06*	0.07 *0.11*	0.25 *0.40*	0.03 *0.06*	55.9 *89.4*	2.25 *3.61*	150.6 *241.0*
1/25- 1/31	43.3 *69.3*	10.8 *17.1*	105.1 *168.2*	8.7 *13.9*	0.iw *1.30*	0.07 *0.11*	0.17 *0.27*	0.22 *0.35*	0.02 *0.03*	69.7 *99.2*	2.07 *4.02*	145.4 *260.5*
2/01- 2/07	45.6 *73.0*	10.4 *16.6*	109.6 *175.4*	9.8 *15.6*	0.59 *0.95*	0.06 *0.08*	0.18 *0.28*	0.41 *0.67*	0.02 *0.03*	62.0 *99.2*	2.51 *4.02*	162.9 *260.5*
2/08- 2/14	46.6 *74.5*	10.2 *16.3*	101.1 *161.7*	8.2 *13.1*	0.65 *1.04*	0.07 *0.10*	0.17 *0.27*	0.29 *0.47*	0.02 *0.03*	64.6 *103.2*	2.04 *3.27*	164.5 *263.4*
2/15- 2/21	47.5 *76.0*	10.4 *16.7*	102.0 *163.2*	8.3 *13.2*	0.35 *0.55*	0.04 *0.08*	0.18 *0.28*	0.18 *0.28*	0.01 *0.02*	56.2 *89.8*	2.08 *3.33*	156.4 *250.2*
2/22- 2/28	43.7 *69.9*	10.3 *16.5*	96.6 *154.7*	7.8 *12.6*	1.06 *1.70*	0.06 *0.09*	0.16 *0.27*	0.21 *0.35*	0.16 *0.26*	53.8 *86.2*	1.61 *2.58*	164.5 *263.4*
3/01- 3/07	34.2 *54.7*	7.6 *12.1*	72.9 *116.7*	6.8 *11.0*	0.44 *0.69*	0.03 *0.06*	0.12 *0.20*	0.28 *0.45*	0.02 *0.03*	28.0 *44.9*	1.66 *2.67*	113.3 *181.2*
Total	497.8 *796.4*	109.1 *174.3*	1087.7 *1740.5*	100.2 *160.0*	7.85 *12.54*	0.48 *0.80*	1.36 *2.19*	3.95 *6.31*	2.68 *4.30*	648.6 *1038.0*	24.03 *38.47*	1605.6 *2569.3*

Appendix F, Table 10. MEAN CONCENTRATIONS IN IRRIGATION WATER APPLIED TO CONTROL LYSIMETERS,
(kilograms/hectare)

Dates 1973-1974	Ca	Mg	Na	K	Zn	Cr	Pb	NH_4-N	NO_3-N	SO_4	PO_4	Cl
12/10-12/13	11.8	3.4	0.8	0.1	0.03	0.01	ND	0.02	0	12.4	0.02	1.6
12/14- 1/03	35.4	10.1	2.5	0.4	0.10	0.02	ND	0.07	0.01	37.3	0.06	4.7
1/04- 1/10	11.8	3.4	0.8	0.1	0.03	0.01	ND	0.02	0	12.4	0.02	1.6
1/11- 1/17	23.6	6.7	1.7	0.3	0.07	0.01	ND	0.04	0	24.9	0.03	3.1
1/18- 1/24	23.6	6.7	1.7	0.3	0.07	0.01	ND	0.04	0	24.9	0.03	3.1
1/25- 1/31	23.6	6.7	1.7	0.3	0.07	0.01	ND	0.04	0	24.9	0.03	3.1
2/01 - 2/07	23.6	6.7	1.7	0.3	0.07	0.01	ND	0.04	0	24.9	0.03	3.1
2/08- 2/14	23.6	6.7	1.7	0.3	0.07	0.01	ND	0.04	0	24.9	0.03	3.1
2/15- 2/21	23.6	6.7	1.7	0.3	0.07	0.01	ND	0.04	0	24.9	0.03	3.1
2/22- 2/28	23.6	6.7	1.7	0.3	0.07	0.01	ND	0.04	0	24.9	0.03	3.1
3/01 - 3/07	23.6	6.7	1.7	0.3	0.07	0.01	ND	0.04	0	24.9	0.03	3.1
Total	247.8	70.5	17.7	3.0	0.72	0.12	ND	0.41	0.01	261.3	0.34	32.7

Appendix F, Table 11. LEACHATE PARAMETERS IN TOTAL kg/ha LOST IN TREATMENT 'A'

(6.4 cm of effluent per week plus rainfall)

	Corn			Alfalfa		
Parameter	Box No. 06	Box No. 11	Box No. 18	Box No. 20	Box No. 24	Box No. 29
K	31.6	25.4	36.8	49.4	55.6	37.5
NH_4	0.2	0.6	0.6	1.0	1.0	0.7
NO_3	64.0	27.6	59.0	12.0	31.6	10.8
PO_4	0.2	0.2	0.9	2.4	1.8	1.6
Ca	919	873	769	731	710	671
Mg	293	263	240	207	228	225
Na	809	860	939	1070	1111	1028
Zn	0.2	0.1	0.1	0.2	0.2	0.2
SO_4	1227	1147	1196	1092	1139	1181
Cl	1746	1518	1641	1731	1897	1808

Appendix F, Table 11 (continued). LEACHATE PARAMETERS IN TOTAL kg/ha LOST IN TREATMENT 'B'

(10.2 cm of effluent per week plus rainfall)

	Corn			Alfalfa		
Parameter	Box No. 01	Box No. 12	Box No. 13	Box No. 22	Box No. 27	Box No. 32
K	51.6	72.0	56.4	80.6	36.8	80.8
NH_4	0.3	1.1	1.3	2.5	0.9	3.7
NO_3	88.3	35.6	67.2	38.4	27.2	15.1
PO_4	0.6	5.3	3.0	4.8	1.7	5.2
Ca	1198.	1140.	1039	1166	1260	1162
Mg	384	359	351	339	407	353
Na	1485	1610	1554	1733	1663	1778
Zn	0.3	0.3	0.3	0.2	0.3	0.4
SO_4	1696	1704	1697	1697	1801	1729
Cl	3241	2789	2654	2916	2854	2855

Appendix F, Table 11 (continued). LEACHATE PARAMETERS IN TOTAL kg/ha LOST IN TREATMENT 'C'

(6.4 cm of effluent per week plus rainfall plus fertilizer)

Parameter	Corn Box No. 02	Corn Box No. 10	Corn Box No. 15	Alfalfa Box No. 23	Alfalfa Box No. 25	Alfalfa Box No. 31
K	54.5	37.4	40.5	55.0	30.3	55.1
NH_4	0.3	0.3	1.7	1.1	0.7	3.3
NO_3	383	271	224	49.8	16.6	14.5
PO_4	1.3	2.1	0.4	1.6	1.9	2.0
Ca	1030	1067	965	756	818	718
Mg	314	358	285	218	241	222
Na	951	897	957	1094	1132	1148
Zn	0.1	0.2	0.1	0.1	0.2	0.2
SO_4	1126	1208	1107	1134	1209	1181
Cl	1707	1640	1815	1890	1961	1938

Appendix F, Table 11 (continued). LEACHATE PARAMETERS IN TOTAL kg/ha LOST IN TREATMENT 'D'

(10.2 cm of effluent per week plus rainfall plus fertilizer)

Parameter	Corn Box No. 05	Corn Box No. 08	Corn Box No. 14	Alfalfa Box No. 22	Alfalfa Box No. 27	Alfalfa Box No. 32
K	67.0	62.4	76.4	80.6	36.8	80.8
NH_4	0.9	2.6	24.9	2.5	0.9	3.7
NO_3	81.4	76.4	57.2	38.4	27.2	15.1
PO_4	0.6	0.7	1.6	4.8	1.7	5.2
Ca	1017	1229	1084	1166	1260	1162
Mg	360	370	341	339	407	353
Na	1653	1527	1568	1733	1663	1779
Zn	0.3	0.2	0.3	0.2	0.3	0.4
SO_4	1731	1775	1675	1697	1801	1730
Cl	2940	2516	2789	2917	2854	2855

Appendix F, Table 11 (continued). LEACHATE PARAMETERS IN TOTAL kg/ha LOST IN TREATMENT 'E'

(6.4 cm of effluent per week plus rainfall plus lime)

	Corn			Alfalfa		
Parameter	Box No. 03	Box No. 09	Box No. 17	Box No. 21	Box No. 28	Box No. 33
K	37.5	30.7	34.5	42.5	47.6	44.0
NH_4	0.4	0.3	0.6	1.2	2.0	1.5
NO_3	43.2	29.4	37.3	17.4	9.0	8.0
PO_4	1.1	0.2	1.0	2.5	3.3	2.0
Ca	833	828	869	960	698	870
Mg	276	249	283	266	231	242
Na	863	850	956	1082	1078	1100
Zn	0.1	0.2	0.2	0.2	0.2	0.2
SO_4	1348	1204	1459	1225	1186	1204
Cl	1760	1626	1761	2013	1827	1901

Appendix F, Table 11 (continued). LEACHATE PARAMETERS IN TOTAL kg/ha LOST IN TREATMENT 'F'

(2.5 cm well water irrigation with fertilizer)

	Corn			Alfalfa		
Parameter	Box No. 04	Box No. 07	Box No. 16	Box No. 19	Box No. 26	Box No. 30
K	14.6	6.1	14.6	6.3	7.5	5.4
NH_4	0.1	0	0.1	0	0.2	0.1
NO_3	127.8	101.0	90.3	3.5	1.2	1.0
PO_4	0.1	0.1	0.1	0.8	0.2	0.1
Ca	440	352	300	301	256	306
Mg	125	116	94.8	86.5	73.2	86.1
Na	25.6	21.7	20.2	17.1	21.9	54.5
Zn	0	0	0.1	0.1	0	0.1
SO_4	441	520	515	568	591	564
Cl	362	172	103	81	81	101

Appendix F, Table 12. THE EFFECT OF NITROGEN APPLIED AS 28 PERCENT LIQUID ON THE NITRATE CONTENT OF THE SOIL AND CORN STALKS

		Circle 16 (heavy soil)			Circle 16 (sandy soil)		
		Soil nitrate test			Soil nitrate test		
Date	Nitrogen applied, kg/ha	Surface to 10 cm, kg/ha	10 to 20 cm, kg/ha	Stalk nitrate test	Surface to 10 cm, kg/ha	10 to 20 cm, kg/ha	Stalk nitrate test
June 23 (before application)		3.40	1.10	Low	2.00	1.70	Very low
June 23 (after application)	13.5	6.30	4.10	Low	7.20	3.40	
June 30		6.70	2.20	Blank	4.00	2.00	Trace
July 3		8.40	3.40	Blank			
July 5	24.2						
July 8		8.20	2.80	Low to medium			
July 11 to 17	16.0						
July 17		6.50	2.80	Medium to high			
July 18 to 31	37.2						
August 1		17.2	6.70	Low to medium	13.3	9.30	High
August 1 and 2	8.60						
August 18				50 percent blank 50 percent high	8.50	4.60	High

Appendix F, Table 13. THE EFFECT OF NITROGEN APPLIED AS 28 PERCENT LIQUID ON THE NITRATE CONTENT OF THE SOIL AND CORN STALKS

Circle number	Date	Nitrogen applied, kg/ha	Soil nitrate test, kg/ha		Stalk nitrate test
			Surface to 10 cm	10 to 20 cm	
20	June 30[a]		4.70	3.80	Blank
	June 30[b]	10.9	29.8	8.10	
	July 3		10.5	6.90	Low to medium
	July 8		3.90	2.80	Low to blank
	July 11 to 17	16.0			
	July 17		36.1	12.9	Low to medium
	July 18 to 31	37.2			
	August 1		29.7	16.6	High
	August 1 and 2	8.60			
	August 18		14.9	8.30	High
21	June 23[a]		3.50	3.00	Very low
	June 30[b]	6.50	9.00	3.90	
	June 30		8.70	3.00	Trace
	July 3		8.40	4.90	Blank
	July 5	23.4			
	July 8		14.6	4.90	Medium to high
	July 11 to 17	16.0			
	July 17		3.40	2.10	Low to blank
	July 18 to 31	37.2			
	August 1		14.3	5.30	Medium to high
	August 1 and 2	8.60			
	August 18		3.50	2.50	Blank
54	June 30[a]		7.60	6.90	Blank
	June 30[b]	10.8	26.2	9.20	
	July 3		14.3	9.60	High
	July 8		4.30	2.60	Low to medium
	July 11 to 17	13.0			
	July 17		31.3	26.2	High
	July 18 to 31	30.5			
	August 1		17.4	11.5	High
	August 1 and 2	17.8			
	August 18		15.0	12.1	Medium

[a] before application [b] after application

Appendix F, Table 14. SOIL ANALYSIS REPORT

Upper values are means. Lower values *(italics)* are standard deviations

Parameter	Soil type	Fall 1973 Pre-irrigation, depth in cm 0-31	31-61	61-91	Fall 1974 Post-irrigation, depth in cm 0-31	31-61	61-91	Spring 1975 Pre-irrigation, depth in cm 0-31	31-61	61-91
pH	Rubicon	5.1 *0.3*	5.4 *0.3*	5.7 *0.3*	6.3 *0.6*	5.8 *0.6*	6.1 *0.6*	6.1 *0.4*	5.7 *0.6*	5.5 *0.4*
	Roscommon	5.8 *0.5*	6.2 *0.9*	6.5 *0.9*	6.3 *0.4*	6.5 *0.3*	6.6 *0.4*	6.4 *0.6*	6.4 *1.1*	6.3 *1.1*
	Au Gres	5.5 *1.0*	5.7 *0.6*	5.9 *0.7*	6.0 *0.8*	5.6 *0.6*	5.6 *0.8*	5.9 *0.6*	5.7 *0.8*	5.9 *0.8*
	Granby	6.8 *1.0*	7.2 *1.2*	7.8 *0.4*	6.4 *0.6*	6.7 *0.9*	7.0 *1.2*	6.7 *0.5*	6.9 *0.9*	7.4 *0.7*
Buffer pH	Rubicon	6.8 *0.1*	7.0 *0.1*	7.3 *0.1*	6.8 *0.1*	7.0 *0.1*	7.1 *0.1*	6.8 *0.1*	6.9 *0*	
	Roscommon	7.0 *0.3*	7.1 *0.2*	7.2 *0.3*	6.8 *0.1*	7.2 *0.2*	7.2 *0.1*	6.9 *0*		6.5 *0*
	Au Gres	6.7 *0.4*	7.1 *0.3*	7.3 *0.2*	6.5 *0.6*	6.6 *0.6*	6.8 *0.2*	6.3 *0.5*	6.4 *0.5*	6.5 *0.2*
	Granby	6.0 *0.5*	6.1 *1.0*		6.3 *0.6*	6.6 *1.1*	7.3 *0*	6.2 *0.4*	5.6 *0*	
Exchange Na, kg/ha	Rubicon	3.8 *0.9*	3.4 *0.6*	2.4 *0.9*	65.0 *21.0*	32.7 *13.0*	17.4 *6.8*	40.2 *19.4*	22.6 *12.4*	9.0 *3.7*
	Roscommon	8.3 *5.3*	3.8 *1.7*	3.4 *1.7*	98.0 *52.0*	38.7 *22.2*	33.5 *23.0*	51.9 *70.7*	26.3 *17.9*	17.8 *11.8*
	Au Gres	6.3 *2.7*	4.3 *1.8*	5.3 *5.9*	69.6 *29.1*	26.6 *9.8*	26.3 *10.8*	36.5 *24.5*	20.8 *23.5*	14.9 *15.9*
	Granby	86.3 *113*	50.9 *73.1*	14.0 *15.0*	104 *99.9*	31.4 *37.2*	10.5 *17.8*	90.0 *131*	56.3 *52.4*	35.9 *37.5*

Appendix F, Table 14 (continued). SOIL ANALYSIS REPORT
Upper values are means. Lower values *(italics)* are standard deviations

		Fall 1973 Pre-irrigation, depth in cm			Fall 1974 Post-irrigation, depth in cm			Spring 1975 Pre-irrigation, depth in cm		
Parameter	Soil type	0-31	31-61	61-91	0-31	31-61	61-91	0-31	31-61	61-91
Exchange Ca, kg/ha	Rubicon	74.6	39.7	22.2	418	40.0	22.4	317	48.3	12.8
		92.9	*31.7*	*18.3*	*357*	*52.9*	*22.1*	*186*	*36.2*	*3.0*
	Roscommon	587	224	172	781	108	99.3	725	168	115
		375	*167*	*130*	*518*	*58.5*	*69.8*	*469*	*132*	*96.6*
	Au Gres	396	152	85.0	352	57.8	28.9	447	98.6	52.2
		283	*192*	*80.4*	*212*	*43.0*	*25.0*	*336*	*128*	*51.2*
	Granby	6900	3020	1230	4250	1370	565	4350	2640	1560
		10300	*4620*	*1650*	*5180*	*2980*	*958*	*3900*	*3220*	*2630*
Exchange Mg, kg/ha	Rubicon	8.1	5.0	2.5	42.9	8.9	3.9	42.4	7.5	2.1
		5.8	*3.7*	*1.5*	*24.4*	*9.0*	*3.5*	*16.1*	*5.0*	*1.1*
	Roscommon	75.0	33.5	23.8	77.2	16.7	10.2	84.7	28.1	19.6
		81.4	*44.3*	*30.8*	*74.2*	*19.1*	*7.3*	*64.9*	*25.2*	*21.4*
	Au Gres	26.8	11.8	9.1	26.0	6.6	4.5	52.8	12.8	7.1
		14.8	*12.6*	*8.7*	*4.8*	*3.6*	*4.3*	*30.6*	*12.1*	*7.1*
	Granby	664	298	137	305	221	83.8	464	343	205
		836	*503*	*135*	*229*	*933*	*74.9*	*481*	*479*	*195*
Exchange K, kg/ha	Rubicon	40.1	19.5	10.1	75.1	35.9	15.0	67.0	27.1	10.5
		25.4	*15.1*	*6.5*	*22.1*	*18.7*	*6.2*	*26.0*	*16.1*	*3.2*
	Roscommon	25.1	10.4	8.4	65.5	22.2	18.0	48.6	15.0	12.6
		9.3	*4.6*	*3.8*	*24.4*	*19.2*	*18.3*	*30.3*	*6.8*	*7.6*
	Au Gres	36.3	14.8	12.9	55.9	17.3	10.4	53.2	17.8	12.8
		15.4	*11.7*	*5.8*	*36.0*	*10.4*	*4.4*	*34.7*	*7.2*	*6.3*
	Granby	78.0	32.6	21.7	63.7	16.7	13.2	106	34.9	21.4
		53.1	*24.8*	*11.4*	*38.2*	*13.7*	*4.1*	*68.7*	*21.0*	*11.8*

Appendix F, Table 14 (continued). SOIL ANALYSIS REPORT
Upper values are means. Lower values *(italics)* are standard deviations

		Fall 1973 Pre-irrigation, depth in cm			Fall 1974 Post-irrigation, depth in cm			Spring 1975 Pre-irrigation, depth in cm		
Parameter	Soil type	0-31	31-61	61-91	0-31	31-61	61-91	0-31	31-61	61-91
Available NO_3-N, kg/ha	Rubicon	7.1	2.5	1.5	5.2	1.6	0.8	6.1	1.3	0.8
		4.3	*1.7*	*1.7*	*2.8*	*1.0*	*0.6*	*3.5*	*0.9*	*0.6*
	Roscommon	12.7	5.3	2.7	8.6	2.8	2.2	5.8	1.0	0.7
		23.1	*11.8*	*5.6*	*10.1*	*4.3*	*2.1*	*3.2*	*0.4*	*0.3*
	Au Gres	10.9	12.6	0.8	5.4	1.9	1.3	6.9	1.3	1.6
		5.5	*25.8*	*0.6*	*3.8*	*1.7*	*1.1*	*3.0*	*0.6*	*1.9*
	Granby	87.2	35.0	1.9	27.1	3.6	2.3	28.6	7.5	1.8
		115	*57.6*	*1.1*	*35.4*	*3.0*	*2.8*	*32.4*	*8.1*	*1.1*
Available NH_4-N, kg/ha	Rubicon	21.3	12.0	9.8	14.2	11.4	9.4	15.5	12.8	12.3
		9.3	*6.3*	*5.7*	*2.4*	*2.7*	*2.7*	*2.7*	*2.8*	*2.7*
	Roscommon	12.1	7.3	7.2	11.5	6.9	6.6	14.9	12.4	12.6
		3.1	*3.0*	*2.6*	*2.2*	*0.8*	*0.9*	*4.5*	*1.5*	*3.7*
	Au Gres	12.9	6.9	6.2	21.6	12.3	12.2	15.8	11.1	11.4
		4.5	*2.7*	*1.7*	*13.8*	*2.2*	*1.8*	*9.1*	*2.6*	*2.1*
	Granby	20.7	17.3	8.5	16.6	12.7	8.7	23.0	24.7	14.9
		20.8	*22.8*	*3.0*	*11.7*	*11.0*	*1.5*	*10.3*	*13.6*	*4.5*
Available P, kg/ha	Rubicon	87.4	102	73.0	64.9	94.8	74.2	99.1	105	96.5
		47.9	*37.9*	*20.7*	*17.4*	*51.8*	*35.2*	*54.6*	*56.3*	*42.2*
	Roscommon	18.5	12.9	35.3	28.9	18.5	19.1	19.7	21.6	45.3
		13.0	*9.0*	*54.6*	*30.8*	*12.2*	*10.3*	*14.7*	*14.9*	*67.7*
	Au Gres	25.2	39.5	29.8	24.0	21.9	31.5	27.0	29.5	29.2
		20.5	*53.7*	*16.7*	*24.3*	*19.4*	*13.0*	*27.6*	*29.2*	*12.3*
	Granby	23.4	12.3	18.3	22.6	11.5	16.8	15.6	8.5	10.8
		25.8	*10.9*	*12.6*	*23.1*	*7.4*	*9.2*	*11.0*	*8.0*	*6.6*

Appendix F, Table 14 (continued). SOIL ANALYSIS REPORT
Upper values are means. Lower values *(italics)* are standard deviations

Parameter	Soil type	Fall 1973 Pre-irrigation, depth in cm			Fall 1974 Post-irrigation, depth in cm			Spring 1975 Pre-irrigation, depth in cm		
		0-31	31-61	61-91	0-31	31-61	61-91	0-31	31-61	61-91
Organic matter, percent	Rubicon	1.9	0.9	0.4	2.3	1.1	0.6	2.8	1.3	0.6
		0.3	*0.1*	*0.1*	*0.4*	*0.1*	*0.1*	*0.8*	*0.2*	*0.2*
	Roscommon	2.5	0.9	0.6	3.1	0.9	0.5	3.1	1.1	0.9
		0.7	*0.6*	*0.4*	*0.9*	*0.4*	*0.1*	*1.5*	*0.4*	*0.8*
	Au Gres	3.3	1.1	0.6	3.7	2.2	1.1	4.4	1.7	1.0
		1.4	*0.7*	*0.2*	*1.9*	*1.8*	*0.5*	*2.2*	*1.5*	*0.9*
	Granby	17.8	13.1	2.5	15.7	5.5	1.4	17.7	10.5	4.2
		21.9	*22.5*	*3.6*	*22.7*	*11.7*	*1.4*	*27.0*	*18.7*	*7.5*
Cation exchange capacity, MEQ/100g	Rubicon	9.5	6.2	6.8	11.3	6.9	3.4	10.4	6.4	3.2
		1.2	*0.8*	*0.6*	*2.7*	*0.8*	*0.9*	*2.1*	*1.2*	*0.5*
	Roscommon	12.1	5.9	6.1	13.4	4.8	2.5	11.8	5.2	4.8
		3.4	*3.3*	*3.4*	*3.3*	*2.9*	*1.1*	*4.7*	*2.5*	*3.5*
	Au Gres	15.0	6.8	3.8	15.2	11.9	5.8	16.3	10.6	6.4
		7.2	*4.8*	*1.4*	*9.0*	*8.9*	*4.1*	*9.1*	*7.4*	*5.2*
	Granby	51.6	27.9	5.2	46.3	15.8	3.0	47.3	31.2	9.6
		53.9	*47.7*	*6.0*	*55.6*	*30.4*	*1.8*	*56.7*	*46.6*	*13.7*

Appendix F, Table 15. ANALYTICAL RESULTS OF REFRACTORY ORGANICS IN THE CORN[a]

in parts per million

	END[b]	HE[c]	DDE[d]	DDD[e]	DDT[f]	EST. PCB[g]	Dieldrin[h]	BHC[i]	Lindane[j]	HCB[k]
Corn A	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005
Corn B	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005
Corn C	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005
Corn D	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005
Corn E	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005
Corn F	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.005	<0.005	<0.005

[a] Tested at WARF Institute, Inc., Madison, Wisconsin. WARF Number 5102795-2800

[b] END (Endrin) Insecticide. Toxicity, acute oral LD_{50} for rats ranges from 5 mg/kg (female) to 45 mg/kg (male)

[c] HE (Heptachlor) Insecticide. Toxicity, acute oral LD_{50} (male rat), 40 to 188 mg/kg

[d] DDE (Degradation product of DDT

[e] DDD or TDE Insecticide. Structurally and chemically related to DDT. Toxicity, acute oral LD_{50} (rat), 3,400 mg/kg

[f] DDT Insecticide. Toxicity, acute oral toxicity for man has been established at 250 mg/kg. Acute oral LD_{50} (rat) for technical DDT, 113 mg/kg

[g] EST. PCB (Polychlorinated biphenyls). Toxicity, acute oral LD_{50} range from 4,000 to 19,000 mg/kg (rat)

[h] Dieldrin Insecticide. Toxicity, acute oral LD_{50} (rat), 60 mg/kg

[i] BHC Insecticide. Toxicity, see Lindane below.

[j] Lindane (Gamma BHC) Insecticide. Toxicity, acute oral LD_{50} (male rat), 88 to 125 mg/kg

[k] HCB (Hexachlorobenzene) Seed protectant

Appendix G, Table 1. LOCATIONS OF WHEAT PLANTINGS, 1974-1975

Location	Number of hectares
Southeast corner of circle 25	1.10
Southwest corner of circle 24	1.90
Northeast corner of circle 20	2.40
East of circles 21 and 22	4.10
East of lagoon and south of circle 36	4.30
Between lagoon and Apple Avenue	41.3
Southeast corner of circle 53	2.70
Southeast corner of circle 11	0.90
East of Administration Building	3.60
West of lagoon	11.9
South of Apple Avenue	1.30
Northeast corner of circle 44	3.40
South of circle 51	21.2
South of circle 50	11.2
Total	111.3

Appendix G, Table 2. 1974 CORN PLANTING DATA

Circle Number	Variety	Maturity, days	Date planted
1	Trojan TX 70	70	6/11/74
	Trojan TXS 85	85	6/11/74
2	Trojan TX 70	70	6/12/74
	Trojan TXS 85	85	6/12/74
3	Pioneer 3965	90	5/15/74
4	Funks 4195	95	5/15/74
5	Pioneer 3965	90	5/15/74
6	Trojan TXS 94	94	5/15/74
7	Cowbell 292/145	95	5/10/74
8	Acco 1301	95	5/10/74
9	Funks 4195	95	5/ 9/74
10	Cowbell 292/145	95	5/10/74
11	Funks 4195	95	5/10/74
12	Trojan TXS 94	94	5/21/74
13	Pioneer 3958	100	7/ 7/74
14	Funks 4195	95	5/ 7/74
15	Trojan TX 92	92	4/23/74
16	Trojan TX 92	92	4/25/74
17	Funks 4343	102	4/30/74
18	Pioneer 3958	100	5/ 7/74
19	Trojan TX 70	70	5/ 7/74
20	Funks 4195	95	5/ 6/74
21	Pioneer 3956 A	95	5/ 6/74
22	Pioneer 3958	100	5/ 9/74
23	Funks 5150	85	6/ 4/74
	Teweles 53	90	6/ 4/74
24	Jacques JX 62	95	6/ 3/74
	Trojan TX 90	90	6/ 3/74
25	NK PX 13	88	5/24/74
	Pioneer 3958	100	5/24/74
27	Funks 4195	95	5/20/74
	Trojan TXS 94	94	5/20/74
28	Trojan TXS 94	94	5/20/74
	Funks 4195	95	5/20/74

Appendix G, Table 2 (continued). 1974 CORN PLANTING DATA

Circle	Variety	Maturity, days	Date planted
29	Funks 4195	95	5/20/74
	Trojan TXS94	94	5/20/74
30	Trojan TXS94	94	5/23/74
	NK 446	95	5/23/74
31	Trojan TXS85	85	5/24/74
	Trojan TX70	70	5/24/74
31 A	Trojan TX70	70	6/13/74
32	Trojan TXS85	85	5/24/74
33	Trojan TXS85	85	5/23/74
34	Funks 4195	95	5/22/74
	Teweles 53	90	5/22/74
35	Trojan TXS94	94	5/20/74
	Teweles 53	90	5/22/74
37	Trojan TX70	70	6/15/74
39	Trojan TX70	70	6/13/74
40	Pioneer 3965	90	5/30/74
	Pioneer 3853	100	5/30/74
41	Acco 2901	105	5/ 1/74
	Cowbell 7300	105	5/ 1/74
	Cowbell 7440	105	5/ 1/74
42	Jacques JX170	105	5/ 2/74
	Acco 2901	105	5/ 2/74
43	Teweles 53	90	5/ 4/74
44	Funks 4343	102	5/ 4/74
	Pioneer 3956	95	5/ 4/74
45	Pioneer 3956 A	95	5/ 4/74
46	Trojan TXS94	94	5/ 4/74
47	Jacques JX170	105	5/ 4/74
	Teweles 53	90	5/ 6/74
48	Pioneer 3956 A	95	5/ 2/74
50	Pioneer 3956 A	95	5/ 4/74
51	Funks 5150	90	6/ 5/74
	Trojan TX70	70	6/ 5/74
54	Trojan TXS85	85	5/29/74
	Pioneer 3981	85	5/29/74

Appendix G, Table 3. 1974 HERBICIDE APPLICATION

Circle numbers	Herbicide	Amount per hectare	Application method
1-4, 16-18, 20, 22, 40, 54	Lasso	4.70 liters	Aerial
	Atrazine	1.70 kilograms	Aerial
15, 19, 21, 23-25	Lasso	4.70 liters	Aerial
	Atrazine	1.70 kilograms	Aerial
	Weed oil	9.40 liters	Ground
	Atrazine	2.20 kilograms	Ground
27-31, 32-35	Lasso	4.70 liters	Aerial
	Atrazine	2.20 kilograms	Aerial
	Weed oil	9.40 liters	Ground
	Atrazine	2.20 kilograms	Ground
31 A, 37	Lasso	4.70 liters	Aerial
	Atrazine	2.20 kilograms	Aerial
39	Sutan	6.30 liters	Ground
	Atrazine	1.70 kilograms	Ground
41, 42	Sutan	4.70 liters	Ground
	Atrazine	1.70 kilograms	Ground
	Weed oil	9.40 liters	Ground
	Atrazine	2.20 kilograms	Ground
43, 51	Sutan	6.30 liters	Ground
	Atrazine	2.20 kilograms	Ground
44, 46	Sutan	6.30 liters	Ground
	Atrazine	2.20 kilograms	Ground
	Weed oil	9.40 liters	Ground
	Atrazine	2.20 kilograms	Ground
45, 47, 48, 50	Sutan	4.70 liters	Ground
	Atrazine	1.70 kilograms	Ground

Appendix G, Table 4. 1974 FERTILIZER APPLICATION

Circle Number	kg/ha			Circle Number	kg/ha		
	N	P	K		N	P	K
1	22	0	0	27	0	0	0
2	34	0	37	28	0	0	0
3	34	0	37	29	0	0	0
4	34	0	37	30	72	22	101
5	34	0	37	31	52	0	0
6	34	0	37	31 A	0	0	0
7	34	0	37	32	0	0	0
8	34	0	37	33	72	22	0
9	34	0	26	34	0	0	0
10	27	0	37	35	0	0	0
11	85	0	26	37	52	0	0
12	85	0	127	39	0	0	0
13	34	0	37	40	52	0	0
14	34	0	37	41	93	0	0
15	54	22	37	42	93	0	0
16	54	22	138	43	93	0	0
17	34	0	138	44	132	0	0
18	34	0	37	45	93	0	0
19	34	0	37	46	93	0	0
20	34	0	0	47	93	0	0
21	15	0	0	48	93	0	0
22	34	0	101	49	0	0	202
23	85	0	26	50	93	0	0
24	34	0	26	51	41	0	0
25	72	0	0	54	34	0	37

Appendix G, Table 5. 1974 NITROGEN, kg/ha

Circle number	Wastewater nitrogen: Before crop	Wastewater nitrogen: Crop	Wastewater nitrogen: After crop	Wastewater nitrogen: Total	Fertilizer	Available[a]	Total[b]
1	1.50	22.3	64.1	87.9	22.4	44.7	110
2	6.70	42.8	58.3	108	33.6	76.4	141
3	0	42.4	55.2	97.6	33.6	76.0	131
4	0.30	44.8	50.7	95.8	33.6	78.4	129
5	0	40.0	75.7	116	33.6	73.6	149
6	0.30	42.8	53.5	96.6	33.6	76.4	130
7	0	43.0	80.7	124	33.6	76.6	157
8	0	40.2	73.8	114	33.6	73.8	148
9	0	39.6	71.7	111	33.6	73.2	145
10	0	35.5	66.5	102	26.9	62.4	129
11	0	39.7	65.8	106	85.2	125	191
12	1.30	33.3	67.7	102	85.2	119	188
13	0	41.9	65.7	108	33.6	75.5	[illegible]
14	0	44.2	51.2	95.4	33.6	77.8	129
15	0	46.2	25.0	71.2	53.8	100	125
16	0	43.8	36.0	79.8	53.8	97.6	134
17	0	41.0	47.3	88.3	33.6	74.6	122
18	0	41.8	63.1	105	33.6	75.4	139
19	0	37.7	33.3	71.0	33.6	71.3	105
20	0	39.6	45.8	85.4	33.6	73.2	119
21	0	37.7	31.6	69.3	14.6	52.3	83.9
22	0	47.1	46.7	93.8	33.6	80.7	127
23	2.20	32.6	51.8	86.6	85.2	118	172
24	1.00	40.7	43.4	85.1	33.6	74.3	119
25	0	16.0	37.3	53.3	71.7	87.7	125

[a] Available nitrogen equals Crop nitrogen plus Fertilizer nitrogen

[b] Total nitrogen equals Wastewater nitrogen plus Fertilizer nitrogen

Appendix G, Table 5 (continued). 1974 NITROGEN, kg/ha

Circle number	Wastewater nitrogen				Fertilizer	Available[a]	Total[b]
	Before crop	Crop	After crop	Total			
27[c]	0	15.7	60.9	76.6	0	15.7	76.6
28[c]	0	72.3	76.8	149	0	72.3	149
29[c]	0	65.4	30.8	96.2	0	65.3	96.2
30	0	16.6	0	16.6	71.7	88.3	88.3
31	0	0	35.0	35.0	51.6	51.6	86.6
31 A	0	6.80	3.40	10.2	0	6.80	10.2
32	0	7.60	3.40	11.0	0	7.60	11.0
33	0	25.7	7.10	32.8	71.7	97.4	104
34[c]	0.60	72.7	82.5	156	0	72.7	156
35[c]	0	69.3	30.8	100	0	69.3	100
37	0	0	11.1	11.1	51.6	51.6	62.7
39	0	0.90	1.90	2.80	0	0.90	2.80
40	0	15.2	10.3	25.5	51.6	66.8	77.1
41	0	17.9	24.0	41.9	93.0	111	135
42	0	8.10	23.3	31.4	93.0	101	124
43	0	9.80	24.4	34.3	93.0	103	127
44	0	9.00	12.3	21.3	132	141	154
45	0	25.8	42.4	68.2	93.0	119	161
46	0	17.3	24.4	41.7	93.0	110	135
47	0	3.60	23.5	27.1	93.0	96.6	120
48	0	13.2	29.9	43.1	93.0	106	136
50	0	6.40	15.1	21.5	93.0	99.4	115
51	0	9.60	4.00	13.0	41.5	51.1	55.1
54	2.40	44.9	61.9	109	33.6	78.5	143

[a] Available nitrogen equals Crop nitrogen plus Fertilizer nitrogen
[b] Total nitrogen equals Wastewater nitrogen plus Fertilizer nitrogen
[c] End caps off

Appendix G, Table 6. 1974 PHOSPHORUS APPLIED, kg/ha

Circle number	Wastewater phosphorus During crop	Wastewater phosphorus After crop	Wastewater phosphorus Total	Fertilizer	Available[a]	Total[b]
1	22.1	54.9	77.0	0	22.1	77.0
2	32.8	53.6	86.4	0	32.8	86.4
3	31.2	53.8	85.0	0	31.2	85.0
4	33.4	47.2	80.6	0	33.4	80.6
5	29.5	70.2	99.7	0	29.5	99.7
6	31.9	52.2	84.1	0	31.9	84.1
7	31.7	74.9	107	0	31.7	107
8	29.7	68.4	98.1	0	29.7	98.1
9	29.1	66.6	95.7	0	29.1	95.7
10	26.1	61.6	87.7	0	26.1	87.7
11	29.3	61.1	90.4	0	29.3	90.4
12	26.1	62.8	88.9	0	26.1	88.9
13	30.8	60.9	91.7	0	30.8	91.7
14	32.5	49.1	81.6	0	32.5	81.6
15	34.0	23.9	57.9	22.4	56.4	80.3
16	32.3	39.1	71.4	22.4	54.7	93.8
17	30.2	45.6	75.8	0	30.2	75.8
18	30.7	45.2	75.9	0	30.7	75.9
19	27.7	32.4	60.1	0	27.7	60.1
20	29.1	44.3	73.4	0	29.1	73.4
21	27.7	27.2	54.9	0	27.7	54.9
22	34.6	46.7	81.3	0	34.6	81.3
23	26.9	48.0	74.9	0	26.9	74.9
24	31.2	39.8	71.0	0	31.2	71.0
25	15.2	34.6	49.8	0	15.2	49.8

[a] Available phosphorus equals Crop phosphorus plus Fertilizer phosphorus

[b] Total phosphorus equals Wastewater phosphorus plus Fertilizer phosphorus

Appendix G, Table 6 (continued). 1974 PHOSPHORUS APPLIED, kg/ha

Circle number	Wastewater phosphorus					
	During crop	After crop	Total	Fertilizer	Available[a]	Total[b]
27[c]	6.30	60.4	66.7	0	6.30	66.7
28[c]	53.2	70.6	124	0	53.2	124
29[c]	48.1	28.4	76.5	0	48.1	76.5
30	15.8	0	15.8	22.4	38.2	38.2
31	0	32.6	32.6	0	0	32.6
31 A	6.50	3.10	9.60	0	6.50	9.60
32	7.30	4.00	11.3	0	7.30	11.3
33	24.3	6.80	31.1	22.4	46.7	53.5
34[c]	54.2	75.8	130	0	54.2	130
35[c]	62.3	29.5	91.8	0	62.3	91.8
37	0	10.3	10.3	0	0	10.3
39	0.90	2.40	3.30	0	0.90	3.30
40	14.5	10.0	24.5	0	14.5	24.5
41	16.9	22.0	38.9	0	16.9	38.9
42	7.60	21.4	29.0	0	7.60	29.0
43	9.30	23.0	32.3	0	9.30	32.3
44	8.50	11.4	19.9	0	8.50	19.9
45	24.4	44.6	69.0	0	24.4	69.0
46	16.4	26.8	43.2	0	16.4	43.2
47	3.50	24.8	28.3	0	3.50	28.3
48	12.6	33.0	45.6	0	12.6	45.6
50	6.10	15.9	22.0	0	6.10	22.0
51	9.10	4.80	13.9	0	9.10	13.9
54	36.1	56.7	92.8	0	36.1	92.8

[a] Available phosphorus equals Crop phosphorus plus Fertilizer phosphorus

[b] Total phosphorus equals Wastewater phosphorus plus Fertilizer phosphorus

[c] End caps off

Appendix G, Table 7. 1974 POTASSIUM APPLIED, kg/ha

Circle number	Wastewater potassium During crop	 After crop	 Total	Fertilizer	Available[a]	Total[b]
27[c]	48.8	124	172	0	48.8	172
28[c]	175	152	327	0	175	327
29[c]	134	51,7	186	0	134	186
30	36.4	0	36.4	101	137	137
31	0	68.0	68.0	0	0	68.0
31 A	15.0	6.40	21.4	0	15.0	21.4
32	16.8	7.50	24.3	0	16.8	24.3
33	39.0	10.9	49.9	0	39.0	49.9
34[c]	191	164	354	0	191	354
35[c]	160	67.9	228	0	160	228
37	0	21.9	21.9	0	0	21.9
39	2.10	4.10	6.20	0	2.10	6.20
40	33.2	22.6	55.8	0	33.2	55.8
41	39.2	47.9	87.1	0	39.2	87.1
42	17.6	47.3	64.9	0	17.6	64.9
43	21.4	41.4	62.8	0	21.4	62.8
44	19.5	23.4	42.9	0	19.5	42.9
45	56.3	78.6	135	0	56.3	135
46	37.8	47.2	85.0	0	37.8	85.0
47	8.00	44.5	52.5	0	8.00	52.5
48	29.1	59.4	88.5	0	29.1	88.5
50	18.9	38.6	57.5	0	18.9	57.5
51	21.1	10.1	31.2	0	21.1	31.2
54	110	125	235	37.0	147	272

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[a] Available potassium equals Crop potassium plus Fertilizer potassium

[b] Total potassium equals Wastewater potassium plus Fertilizer potassium

[c] End caps off

Appendix G, Table 7 (continued). 1974 POTASSIUM APPLIED, kg/ha

Circle number	Wastewater potassium: During crop	Wastewater potassium: After crop	Wastewater potassium: Total	Fertilizer	Available[a]	Total[b]
1	52.5	122	175	0	52.5	175
2	101	120	220	37.0	138	257
3	96.4	106	202	37.0	133	239
4	102	107	208	37.0	139	245
5	90.0	139	229	37.0	203	243
6	96.4	103	199	37.0	133	236
7	94.6	150	244	37.0	132	281
8	90.1	136	226	37.0	127	263
9	103	152	255	25.8	129	281
10	78.9	124	203	37.0	116	240
11	87.5	122	210	25.8	113	236
12	77.3	124	202	127	204	328
13	93.1	121	214	37.0	130	251
14	98.5	94.8	193	37.0	136	230
15	108	55.8	164	37.0	145	201
16	101	72.4	174	138	239	312
17	97.5	89.2	187	138	235	325
18	96.4	88.7	185	37.0	133	222
19	88.1	56.4	145	37.0	125	182
20	94.3	86.1	180	0	94.3	180
21	84.7	58.7	143	0	84.7	143
22	111	90.3	201	101	212	302
23	86.5	95.5	182	25.8	112	208
24	101	86.4	187	25.8	127	213
25	34.4	75.5	110	0	34.4	110

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[a] Available potassium equals Crop potassium plus Fertilizer potassium

[b] Total potassium equals Wastewater potassium plus Fertilizer potassium

Appendix G, Table 8. 1974 IRRIGATION, cm

Circle number	Before crop	Crop	After crop	Total	Circle number	Before crop	Crop	After crop	Total
1	6.40	43.7	99.6	149	27[a]	0	71.1	101	172
2	30.2	84.3	97.0	211	28[a]	0	185	128	313
3	0	109	87.1	196	29[a]	0	168	51.3	219
4	1.50	115	89.2	206	30	0	32.5	0	32.5
5	0	103	114	216	31	0	0	52.8	52.8
6	1.50	107	84.6	193	31 A	0	13.5	5.10	18.6
7	0	111	121	232	32	0	15.0	6.60	21.6
8	0	103	111	214	33	0	50.0	14.0	64.0
9	0	102	108	209	34[a]	2.50	187	137	327
10	0	91.2	99.8	191	35[a]	0	157	60.7	218
11	0	102	98.8	201	37	0	0	16.8	16.8
12	5.80	85.3	102	193	39	0	1.80	3.80	5.60
13	0	107	98.6	206	40	0	29.7	18.0	47.7
14	0	113	79.5	193	41	0	35.1	39.9	75.0
15	0	118	49.3	168	42	0	15.7	38.9	54.6
16	0	113	61.2	174	43	0	19.1	31.5	50.6
17	0	105	73.9	179	44	0	17.5	18.5	36.0
18	0	107	73.2	180	45	0	50.3	61.2	112
19	0	96.5	42.9	139	46	0	33.8	36.8	70.6
20	0	102	71.6	173	47	0	7.10	34.0	41.1
21	0	96.5	47.5	144	48	0	25.9	45.2	71.1
22	0	121	75.7	196	50	0	12.4	21.8	34.2
23	10.2	83.6	77.7	172	51	0	18.8	7.90	26.7
24	4.30	104	72.1	181	54	10.7	115	103	229
25	0	31.5	62.7	94.2					

[a] End caps off

Appendix G, Table 9. 1974 CORN HARVEST DATA

Circle Number	Date harvested	Grain moisture content, percent	Metric tons/ hectare	Circle Number	Date harvested	Grain moisture content, percent	Metric tons/ hectare
1	11/23	31.6	0.82	27	11/13	29.4	3.45
2	11/23	36.9	1.07	28	11/14	29.2	2.14
3	10/24	30.9	2.26	29	11/11	27.0	2.70
4	10/28	33.1	0.38	30	11/ 5	29.4	2.01
5	10/26	32.3	2.51	31	12/ 3	22.0	0.06
6	10/25	31.6	2.45	31 A	11/18	25.9	1.00
7	10/25	31.6	2.45	32	11/12	22.0	1.95
8	10/28	31.6	1.88	33	11/11	22.2	1.44
9	11/ 1	34.1	2.20	34	11/29	25.3	2.20
10	10/29	31.9	2.57	35	11/15	23.9	1.26
11	10/30	36.4	1.19	37	NH*	50.0 +	0
12	11/ 2	32.5	3.20	39	11/21	29.2	0.63
13	10/31	33.4	2.64	40	11/16	25.8	2.20
14	11/ 4	28.8	1.19	41	11/20	29.6	2.32
15	10/23	31.2	2.89	42	11/19	29.9	1.00
16	10/23	32.0	2.39	43	10/10	31.1	1.70
17	11/ 6	33.7	1.38	44	11/21	23.1	1.95
18	11/ 8	33.5	1.95	45	10/12	32.0	2.01
19	10/ 1	32.0	2.57	46	10/22	31.2	2.32
20	11/ 4	32.0	2.26	47	10/ 7	33.4	1.00
21	11/ 8	30.7	1.00	48	10/19	30.5	2.20
22	11/ 7	28.5	0.94	50	10/17	30.8	2.51
23	11/10	41.9	1.00	51	11/20	25.7	0.88
24	11/20	40.8	1.38	54	11/14	28.6	1.38
25	12/ 4	26.9	1.44	55		31.2	0.88

*Not harvested

Appendix G, Table 10. 1975-1976 WHEAT

Location	Number of hectares
Around circle 22 and east of circle 21 along Swanson Road	8.40
East of circle 20 and 19 along Swanson Road	8.70
North and west of circle 23	9.10
West and south of circle 24	4.90
Between circles 24 and 25	14.4
Southeast of circle 25	5.30
Between circles 18 and 19	9.40
South of circle 12	2.40
Southeast of circle 11	2.20
Southeast of circle 53	1.20
East of Administration Building	1.70
Northwest of circle 27	10.8
Northeast of circle 27	3.80
North of circle 29 along White Road	2.70
Between circle 29 and 34 along Swanson Road	9.00
East of circles 30 and 33 along Swanson Road	12.7
Between circles 30, 31, 32 and 33	13.4
Between circles 31 and 38	8.90
North and west of circle 40 along Swanson Road	7.90
West of solid waste site	4.00
Around circles 43 and 46	19.70
Northeast of circle 44	4.40
South of circles 51 and 52	13.2
Total	178.2

Appendix G, Table 11. 1975 CORN PLANTING DATA

Circle	Variety	Maturity days	Date planted
3	Jacques JX122A	98	5/ 7/75
4	Trojan TX92	92	5/21/75
5	Jacques JX40	88	5/17/75
6	Pioneer 3873	90	5/17/75
	Jacques JX40	88	5/17/75
7	Pioneer 3873	90	5/19/75
8	Pioneer 3965	90	5/17/75
	Trojan TXS92	92	5/17/75
9	Jacques JX122A	98	5/ 8/75
10	Jacques JX122A	98	5/ 8/75
11	Jacques JX122A	98	5/ 7/75
12	Jacques JX122A	98	5/ 6/75
13	Jacques JX122A	98	5/ 7/75
14	Pioneer 3965	90	5/18/75
15	Funks 4195	95	5/ 1/75
16	Funks 4195	95	5/ 2/75
17	Funks 4195	95	5/ 3/75
18	Jacques JX122A	98	5/ 6/75
	Funks 4195	95	5/ 6/75
19	Funks 4195	95	5/ 6/75
20	Funks 4195	95	5/ 5/75
21	Funks 4195	95	5/ 5/75
22	Funks 4195	95	5/ 6/75
23	Michigan 333	90	5/11/75
24	Michigan 333	90	5/12/75
25	Pioneer 3956A	95	5/20/75
27	Jacques JX122A	98	5/11/75
	Trojan TXS94	94	5/11/75
28	Trojan TXS94	94	5/11/75
29	Trojan TXS94	94	5/11/75
30	Pioneer 3955	90	5/10/75

Appendix G, Table 11 (continued). 1975 CORN PLANTING DATA

Circle	Variety	Maturity, days	Date planted
31	Pioneer 3956 A	95	5/14/75
31 A	Pioneer 3955	90	5/10/75
32	Michigan 333	90	5/11/75
33	Pioneer 3955	90	5/ 9/75
34	Trojan TXS94	94	5/15/75
35	Trojan TXS94	94	5/14/75
36	Trojan TXS85	85	5/27/75
37	Trojan TXS85	85	5/27/75
	Pioneer 3956 A	85	5/27/75
	Pioneer 3965	90	5/27/75
39	Pioneer 3956 A	95	5/17/75
40	Pioneer 3956 A	95	5/16/75
41	Trojan TXS102 A	102	5/13/75
42	Trojan TXS102 A	102	5/14/75
	Jacques JX 40	88	5/14/75
43	Trojan TXS94	94	5/16/75
	Trojan TXS92	92	5/16/75
44	Trojan TXS94	94	5/15/75
	Michigan 407	100	5/15/75
45	Michigan 407	100	5/14/75
46	Michigan 407	100	5/12/75
47	Jacques JX 40	88	5/15/75
	Pioneer 3956 A	95	5/15/75
48	Jacques JX 40	88	5/14/75
49	Jacques JX 1004	95	5/21/75
50	Pioneer 3956 A	95	5/15/75
51	Jacques JX 1004	95	5/21/75
	Trojan TXS85	85	5/21/75
52	Trojan TXS85	85	5/20/75
54	Pioneer 3873	90	5/20/75
	Trojan TX92	92	5/20/75
55	Trojan TX92	92	5/21/75

Appendix G, Table 12. 1975 HERBICIDE APPLICATION

Circle	Herbicide	Amount/hectare	Application method
3, 5, 6, 14-17, 21, 22, 39, 41, 42, 44, 45, 47, 48, 50	Lasso	4.70 liters	Aerial
	Atrazine	1.70 kilograms	Aerial
7, 7, 8, 11, 23-25, 36, 37, 55	Lasso	4.70 liters	Aerial
	Atrazine	1.70 kilograms	Aerial
	Concentrated oil	2.30 liters	Ground
	Atrazine	1.40 kilograms	Ground
9, 10, 12, 13, 18-20, 27-35, 31 A, 40, 43	Lasso	4.70 liters	Aerial
	Atrazine	1.70 kilograms	Aerial
	Concentrated oil	2.30 liters	Ground
	Atrazine	2.80 kilograms	Ground
46	Sutan	6.50 liters	Herbigation
	Concentrated oil	2.30 liters	Ground
	Atrazine	2.80 kilograms	Ground
49, 51, 52	Lasso	4.70 liters	Aerial
	Atrazine	3.40 kilograms	Aerial
	Concentrated oil	2.30 liters	Ground
	Atrazine	1.40 kilograms	Ground
54	Princep	2.00 kilograms (North ½)	Aerial
	Atrazine	1.70 kilograms	Aerial
	Lasso	4.70 liters (North ½)	Aerial
	Atrazine	1.70 kilograms	Aerial
	Concentrated oil	2.30 liters	Ground
	Atrazine	1.40 kilograms	Ground

Appendix G, Table 13. 1975 NITROGEN FERTIGATION, kg/ha

Rig number	Total nitrogen	Rig number	Total nitrogen
1	23.1	28	11.4
2	23.1	29	74.3
3	71.4	30	26.6
4	61.3	31	65.3
5	70.8	31 A	60.2
6	69.4	32	30.4
7	70.7	33	48.0
8	49.0	34	26.3
9	71.4	35	44.9
10	60.3	36	0
11	81.7	37	11.8
12	56.9	39	40.2
13	71.7	40	35.5
14	61.3	41	29.1
15	98.6	42	40.4
16	99.5	43	13.9
17	78.5	44	39.7
18	72.6	45	39.9
19	72.2	46	12.2
20	72.7	47	71.3
21	91.8	48	38.0
22	82.4	49	21.5
23	43.5	50	54.0
24	45.1	51	0
25	90.6	52	0
26	8.20	54	72.1
27	39.0	55	61.3

Appendix G, Table 14. 1975 NITROGEN, kg/ha

Circle number	Wastewater nitrogen						
	Before crop	Crop	After crop	Total	Fertilizer[c]	Available[a]	Total[b]
3	0	71.7	60.0	132	71.4	143	203
4	20.3	77.9	38.9	137	61.3	139	198
5	36.0	81.7	60.8	179	70.8	153	249
6	35.5	81.9	56.4	174	69.4	151	243
7	35.6	88.3	50.7	175	70.7	159	245
8	35.8	75.0	45.7	157	49.0	124	206
9	0	61.0	45.2	106	71.4	132	178
10	0	50.6	41.0	91.6	60.3	111	152
11	0	83.7	42.4	126	81.7	165	208
12	7.40	59.2	44.7	111	56.9	116	168
13	0	57.9	32.7	90.6	71.7	130	162
14	21.3	76.0	44.2	142	61.3	137	203
15	0	55.1	51.8	107	98.6	153	206
16	0	55.0	47.2	102	99.5	155	202
17	0	65.1	49.8	115	78.5	144	193
18	2.70	50.3	39.6	92.6	72.6	123	165
19	4.40	60.2	40.8	105	72.2	132	178
20	5.30	59.9	39.5	105	72.7	133	177
21	6.70	71.5	39.9	118	91.8	163	210
22	7.10	78.9	46.7	133	82.4	161	215
23	10.0	67.3	40.2	118	43.5	111	161
24	4.70	59.9	33.2	97.8	45.1	105	143
25	6.10	21.6	13.2	40.9	90.6	112	132
27	2.90	90.8	41.4	135	39.0	130	174
28	2.90	88.2	33.9	125	11.4	99.6	136
29	2.90	67.7	33.0	104	75.3	143	179

[a] Available nitrogen equals crop nitrogen plus fertilizer nitrogen

[b] Total nitrogen equals wastewater nitrogen plus fertilizer nitrogen

[c] Nitrogen fertilizer was applied as 28% (21.4% NO_3-N, 21.4% NH_4-N and 57.1% Urea-N)

Appendix G, Table 14 (continued). 1975 NITROGEN, kg/ha

Circle number	Wastewater nitrogen				Fertilizer [c]	Available [a]	Total [b]
	Before crop	Crop	After crop	Total			
30	0	82.8	0.60	83.4	26.6	109	110
31	3.40	43.2	10.1	56.7	65.3	109	122
31 A	0.90	29.4	5.30	35.6	60.2	89.6	95.8
32	1.00	24.3	0.30	25.6	30.4	54.7	56.0
33	0	72.4	39.0	111	48.0	120	159
34	9.10	78.9	38.0	126	26.3	105	152
35	1.20	70.6	40.8	113	44.9	116	158
36	0	16.8	5.90	22.7	0	16.8	22.7
37	0	21.1	5.20	26.3	11.8	32.9	38.1
39	4.00	53.1	25.3	82.4	40.2	93.3	123
40	5.00	27.9	13.9	46.8	35.5	63.4	82.3
41	4.10	50.8	8.30	63.2	29.1	79.9	92.3
42	0	47.1	0.80	47.9	40.4	87.5	88.3
43	3.30	29.0	0	32.2	13.9	42.9	46.2
44	7.50	19.7	0.40	27.6	39.7	59.4	67.3
45	10.5	68.0	0.70	79.2	39.9	108	119
46	3.40	25.7	0.10	29.2	12.2	37.9	41.4
47	5.00	48.9	1.00	54.9	71.3	120	126
48	7.40	61.0	9.80	78.2	38.0	99.0	116
49	1.50	22.4	0.40	24.3	21.5	43.9	45.8
50	2.70	21.7	0.60	25.0	54.0	75.7	79.0
51	3.90	17.4	0.30	21.6	0	17.4	21.6
52	8.50	46.5	0.10	55.1	0	46.5	55.1
54	28.9	93.7	29.9	153	72.1	166	225
55	31.3	73.1	32.5	137	61.3	134	198

[a] Available nitrogen equals crop nitrogen plus fertilizer nitrogen

[b] Total nitrogen equals wastewater nitrogen plus fertilizer nitrogen

[c] Nitrogen fertilizer was applied as 28% (21.4% NO_3-N, 21.4% NH_4-N and 57.1% Urea-N)

Appendix G, Table 15. 1975 PHOSPHORUS APPLIED, kg/ha

Circle number	During crop	After crop	Total	Circle number	During crop	After crop	Total
3	16.1	14.7	30.8	29	15.4	8.20	23.6
4	20.5	9.40	29.9	30	19.1	0.10	19.2
5	23.6	14.3	37.9	31	10.0	2.70	12.7
6	23.6	13.5	37.1	31 A	6.70	1.50	8.20
7	26.3	11.9	38.2	32	5.8	0.10	5.90
8	21.3	11.2	32.5	33	16.1	9.40	25.5
9	14.3	11.1	25.4	34	19.2	9.40	28.6
10	10.9	9.80	20.7	35	16.6	10.0	26.6
11	18.0	10.0	28.0	36	3.80	1.60	5.40
12	13.8	10.5	24.3	37	4.30	1.30	5.60
13	14.1	8.00	22.1	39	12.4	5.50	17.9
14	20.4	10.4	30.8	40	7.60	3.10	10.7
15	12.8	12.2	25.0	41	11.5	2.20	13.7
16	12.9	11.3	24.2	42	11.3	0.20	11.5
17	15.4	11.8	27.2	43	7.10	0	7.10
18	12.1	9.30	21.4	44	5.50	0.10	5.60
19	14.6	9.90	24.5	45	16.1	0.10	16.2
20	14.6	9.40	24.0	46	6.20	0	6.20
21	16.5	9.50	26.0	47	12.0	0.20	12.2
22	18.3	11.0	29.3	48	14.3	2.70	17.0
23	15.9	9.40	25.3	49	5.50	0.10	5.60
24	14.3	8.00	22.3	50	5.70	0.10	5.80
25	6.20	3.10	9.30	51	4.90	0.10	5.00
27	20.7	10.1	30.8	52	11.9	0	11.9
28	20.3	8.30	28.6	54	20.0	7.30	27.3
				55	20.4	7.80	28.2

Appendix G, Table 16. 1975 POTASSIUM APPLIED, kg/ha

Circle number	During crop	After crop	Total	Circle number	During crop	After crop	Total
3	94.9	124	218	29	91.1	70.1	161
4	131	81.6	212	30	113	0.30	114
5	153	121	274	31	60.3	22.9	83.2
6	153	113	266	31 A	41.6	12.4	54.0
7	158	103	262	32	40.2	0.60	40.8
8	139	97.3	236	33	97.3	81.4	179
9	85.4	96.5	182	34	115	82.2	197
10	64.6	84.6	149	35	101	72.6	174
11	110	87.1	197	36	23.2	14.1	37.3
12	88.3	91.6	180	37	24.8	12.1	36.9
13	82.6	68.9	152	39	73.3	48.2	122
14	129	96.4	225	40	46.5	27.3	73.8
15	74.2	103	177	41	71.2	19.6	90.8
16	76.3	94.7	171	42	69.4	1.60	71.0
17	90.6	99.3	190	43	44.9	0	44.9
18	75.1	79.5	155	44	37.0	0.90	37.9
19	90.7	82.8	174	45	100	1.60	102
20	91.9	80.6	173	46	39.3	0.30	39.6
21	102	81.4	184	47	75.4	2.10	77.5
22	112	93.5	206	48	88.5	23.1	112
23	99.3	81.9	181	49	34.1	0.80	34.9
24	89.8	80.5	170	50	34.9	1.10	36.0
25	36.0	27.6	63.6	51	30.7	0.60	31.3
27	124	81.6	206	52	73.8	0.30	74.1
28	122	72.0	194	54	125	63.1	188
				55	132	67.5	199

Appendix G, Table 17. 1975 CORN HARVEST DATA

Circle number	Date harvested	Grain moisture content, percent	Metric tons/ hectares	Circle number	Date harvested	Grain moisture content, percent	Metric tons/ hectares
3	10/ 4	27.5	4.40	29	10/27	20.5	4.65
4	10/20	23.2	2.83	30	10/20	20.9	5.09
5	10/ 4	25.8	5.21	31	10/18	23.1	2.64
6	10/ 3	22.8	5.02	31 A	10/17	22.4	3.83
7	10/13	19.5	4.14	32	10/24	21.7	3.83
8	10/14	21.4	3.33	33	10/22	20.3	3.71
9	10/15	21.6	4.96	34	10/25	21.1	3.77
10	10/16	23.2	4.33	35	10/23	20.4	4.33
11	10/11	24.0	5.21	36	10/24	22.1	1.95
12	10/10	25.6	4.58	37	10/27	25.7	2.26
13	10/18	22.0	4.27	39	10/29	20.8	3.45
14	10/17	20.9	3.14	40	10/28	18.5	1.88
15	9/29	26.6	3.77	41	10/28	27.0	2.32
16	10/ 1	25.9	4.46	42	10/29	23.3	3.83
17	10/ 3	25.8	4.46	43	10/31	20.5	3.08
18	10/ 8	27.8	5.65	44	10/ 4	23.1	2.20
19	10/ 6	25.4	5.46	45	11/ 4	24.7	3.96
20	10/ 7	22.9	5.02	46	11/ 4	26.5	3.58
21	10/ 3	26.3	4.77	47	10/30	21.1	4.08
22	10/ 5	26.9	1.82	48	10/31	19.3	3.01
23	10/11	24.5	3.77	49	10/30	22.5	1.76
24	10/16	24.3	4.33	50	10/31	20.9	3.52
25	10/17	22.1	2.07	51	11/ 1	20.5	1.88
27	10/22	23.2	4.58	52	10/ 2	19.3	2.07
28	10/23	22.1	3.96	54	10/21	21.1	3.64
				55	10/21	23.4	3.45

Appendix G, Table 18. WATER APPLICATION FACTORS 1975

Circle number	Critical period[a], cm	Crop, cm	Crop + rain, cm	Total irrigation, cm	Circle number	Critical period[a], cm	Crop, cm	Crop + rain, cm	Total irrigation, cm
3	45.0	102	150	204	29	36.6	100	148	155
4	59.9	111	158	206	30	63.0	111	158	111
5	55.4	133	179	271	31	30.0	60.5	108	80.3
6	55.4	135	181	263	31 A	24.4	40.9	88.4	51.6
7	55.6	137	184	258	32	14.2	34.8	82.6	35.6
8	38.1	121	167	235	33	49.8	96.0	144	166
9	52.8	89.2	136	421	34	61.0	124	172	186
10	26.9	73.7	121	140	35	55.6	107	155	175
11	53.8	117	164	186	36	18.5	22.6	68.3	34.5
12	35.1	88.9	136	181	37	11.9	25.7	72.4	36.1
13	44.2	87.9	135	142	39	39.9	74.2	122	116
14	56.1	108	155	213	40	21.3	43.7	92.5	69.6
15	34.3	72.4	120	165	41	29.7	69.9	119	89.9
16	41.7	73.2	121	171	42	44.7	65.8	115	66.3
17	50.8	86.9	134	151	43	26.7	41.7	90.4	43.9
18	33.0	71.1	118	145	44	15.7	33.5	85.3	38.6
19	42.4	84.8	132	164	45	52.3	93.5	145	103
20	41.4	87.6	135	163	46	15.7	35.3	86.4	40.1
21	39.9	98.0	145	177	47	37.6	70.9	120	73.9
22	48.3	109	156	197	48	48.8	85.9	135	121
23	30.5	97.5	145	176	49	25.1	34.5	82.6	35.6
24	32.0	86.6	134	153	50	15.7	34.0	82.8	35.3
25	10.2	35.3	81.5	62.2	51	12.7	26.9	75.4	30.7
27	62.2	133	181	202	52	41.1	66.8	116	73.9
28	62.7	129	177	185	54	36.1	105	152	198
					55	44.5	107	154	189

[a] Critical period was between June, 30 and August 10

Appendix G, Table 19. 1974-1975 FIELD DAYS AND ASSOCIATED GROWING DEGREE DAYS

Circle number	Field days		GDD		Circle number	Field days		GDD	
	1974	1975	1974	1975		1974	1975	1974	1975
1	165		1761		29	175	169	2018	2402
2	164		1753		30	186	163	1976	2360
3	162	150	1982	2283	31	193	157	1983	2319
4	166	152	2001	2220	31 A	158	160	1744	2356
5	164	140	1991	2186	32	172	166	1978	2382
6	163	139	1987	2181	33	172	166	1982	2385
7	170	147	2008	2217	34	191	163	1994	2367
8	171	150	2015	2267	35	178	162	2013	2341
9	176	160	2054	2371	36		150		2140
10	172	161	2022	2377	37		153	1728	2160
11	173	157	2027	2340	39	161	165	1744	2361
12	165	157	1998	2344	40	170	165	1928	2370
13	177	164	2040	2393	41	204	168	2090	2389
14	181	152	2071	2281	42	202	168	2084	2384
15	183	151	2077	2302	43	159	168	1962	2374
16	181	152	2069	2308	44	202	173	2079	2397
17	190	153	2091	2304	45	161	174	1977	2399
18	185	155	2071	2324	46	168	176	1992	2417
19	147	153	1930	2307	47	155	168	1955	2383
20	182	155	2071	2323	48	171	170	1999	2385
21	186	151	2071	2295	49		162		2284
22	182	152	2071	2300	50	167	169	1992	2383
23	159	153	1871	2294	51	168	164	2036	2287
24	170	157	1890	2331	52		166		2310
25	194	150	1983	2237	54	169	154	1937	2245
27	177	164	2018	2361	55		153		2225
28	178	165	2018	2369					

Appendix G, Table 20. 1975 NOZZLE PLUGGING FOR CORN CROP

Circle number	Percent nozzle plugging	Circle number	Percent nozzle plugging	Circle number	Percent nozzle plugging
3	7	20	1	37	0
4	39	21	33	39	2
5	9	22	82	40	21
6	7	23	27	41	7
7	1	24	0	42	0
8	30	25	0	43	17
9	10	27	2	44	0
10	17	28	0	45	1
11	8	29	5	46	0
12	41	30	0	47	7
13	27	31	13	48	0
14	46	31A	0	49	0
15	56	32	0	50	0
16	22	33	7	51	0
17	17	34	11	52	0
18	7	35	4	54	11
19	4	36	0	55	13

Appendix G, Table 21. 1974-1975 MONTHLY TOTALS RAINFALL AND GROWING DEGREE DAYS

Year/month	Rainfall	GDD
1974		
January	9.02	0
February	3.43	0
March	11.8	24.0
April	8.64[a]	132
May	15.1[a]	178
June	8.64[a]	373
July	2.67	608
August	9.27	523
September	0.64[a]	269
October	5.46[a]	124
November	6.73[a]	28.5
December	3.43	0
1974 total	84.85	2,259.5
1975		
January	5.08	6.50
February	5.08	0
March	5.72[a]	8.00
April	5.08[a]	51.0
May	4.95[a]	392
June	11.9[a]	510
July	4.06	617
August	23.6	579
September	2.41[a]	223
October	2.03[a]	186
November	9.27[a]	78.5
December	6.60	6.00
1975 total	85.84	2,657.00

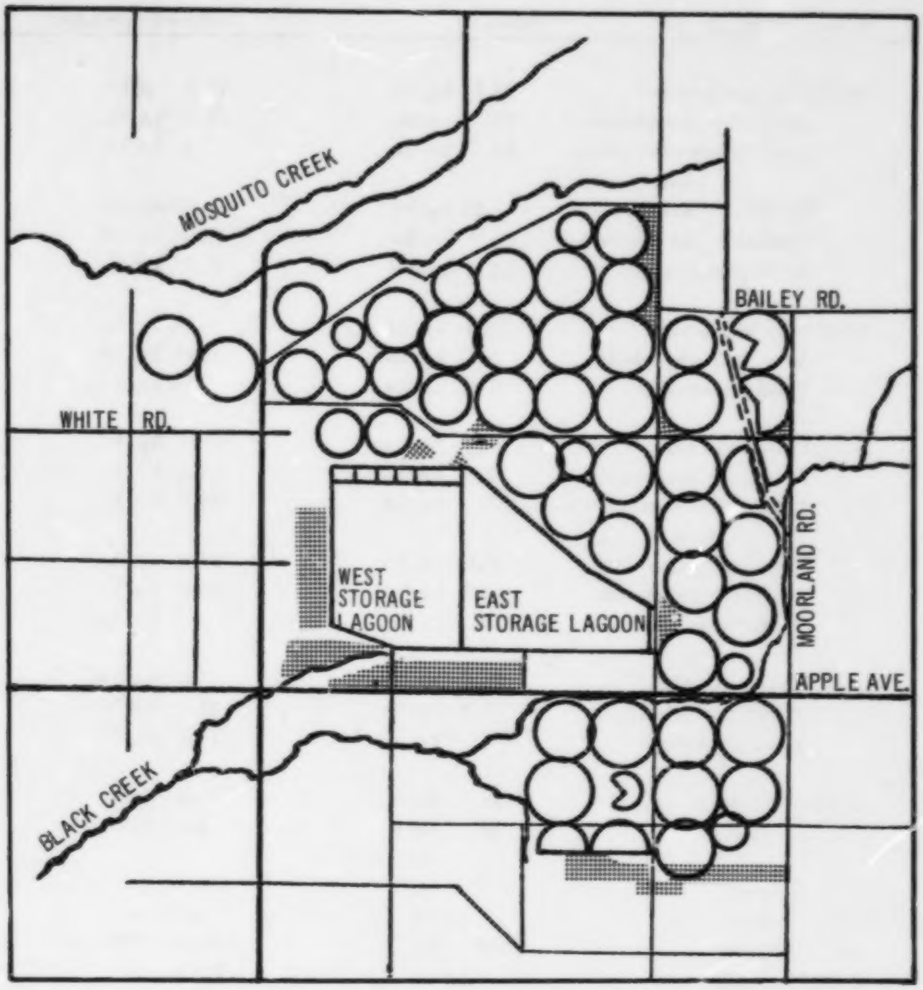
[a] Critical for field operations

Appendix G, Table 22. MEAN AND STANDARD DEVIATION

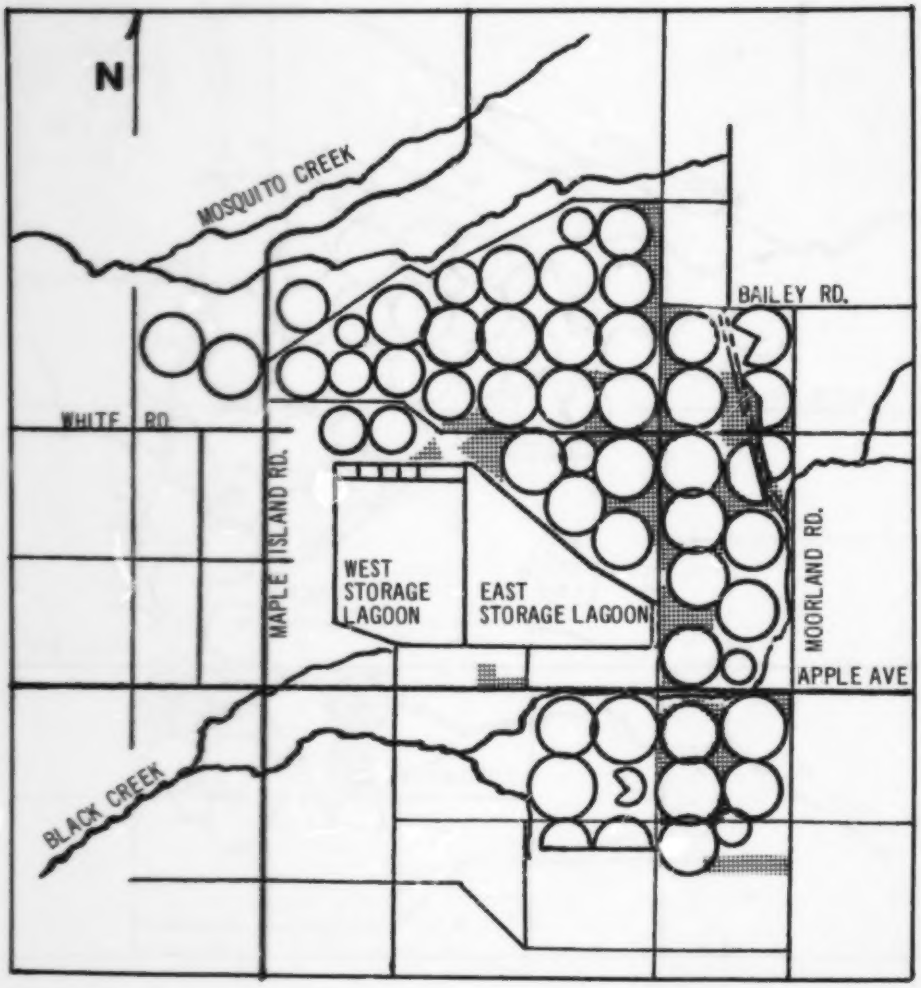
Appendix E Table No.	Column heading	Mean	Standard deviation
2	1974 Maturity days	91.3 days	9.41 days
	Date planted	May 16	13.6 days
4	Nitrogen	45.7 kg/ha	33.6 kg/ha
	Phosphorus	1.79 kg/ha	6.14 kg/ha
	Potassium	28.5 kg/ha	44.3 kg/ha
5	1974 Date harvested	November 6	14.9 days
	Grain moisture content	30.7 percent	4.99 percent
	Metric tons/hectare	1.72 Metric tons/ha	0.80 Metric tons/ha
7	1975 Maturity days	93.3 days	4.15 days
	Date planted	May 13	6.04 days
10	1975 Date harvested	October 19	10.1 days
	Grain moisture content	22.9 percent	2.43 percent
	Metric tons/ha	3.71 Metric tons/ha	1.07 Metric tons/ha
12	Before crop	1.50 cm	4.85 cm
	Crop	75.8 cm	50.3 cm
	After crop	63.9 cm	37.1 cm
	Total	141 cm	82.5 cm
12	Critical cm	38.8 cm	15.1 cm
	Crop cm	82.0 cm	32.9 cm
	Crop cm plus rain	130 cm	32.5 cm
	Total irrigation cm	141 cm	79.4 cm
13	1974 Crop nitrogen	30.8 kg/ha	19.2 kg/ha
	After crop nitrogen	40.8 kg/ha	23.9 kg/ha
	Total wastewater nitrogen	72.0 kg/ha	39.5 kg/ha
	Fertilizer nitrogen	46.7 kg/ha	33.3 kg/ha
	Available nitrogen	77.5 kg/ha	29.6 kg/ha
	Total nitrogen	119 kg/ha	40.5 kg/ha
14	1975 Crop nitrogen	56.9 kg/ha	22.5 kg/ha
	After crop nitrogen	27.1 kg/ha	20.1 kg/ha
	Total wastewater nitrogen	91.6 kg/ha	45.2 kg/ha
	Fertilizer nitrogen	52.0 kg/ha	26.2 kg/ha
	Available nitrogen	109 kg/ha	40.6 kg/ha
	Total nitrogen	144 kg/ha	62.8 kg/ha

Appendix G, Table 22 (continued). MEAN AND STANDARD DEVIATION

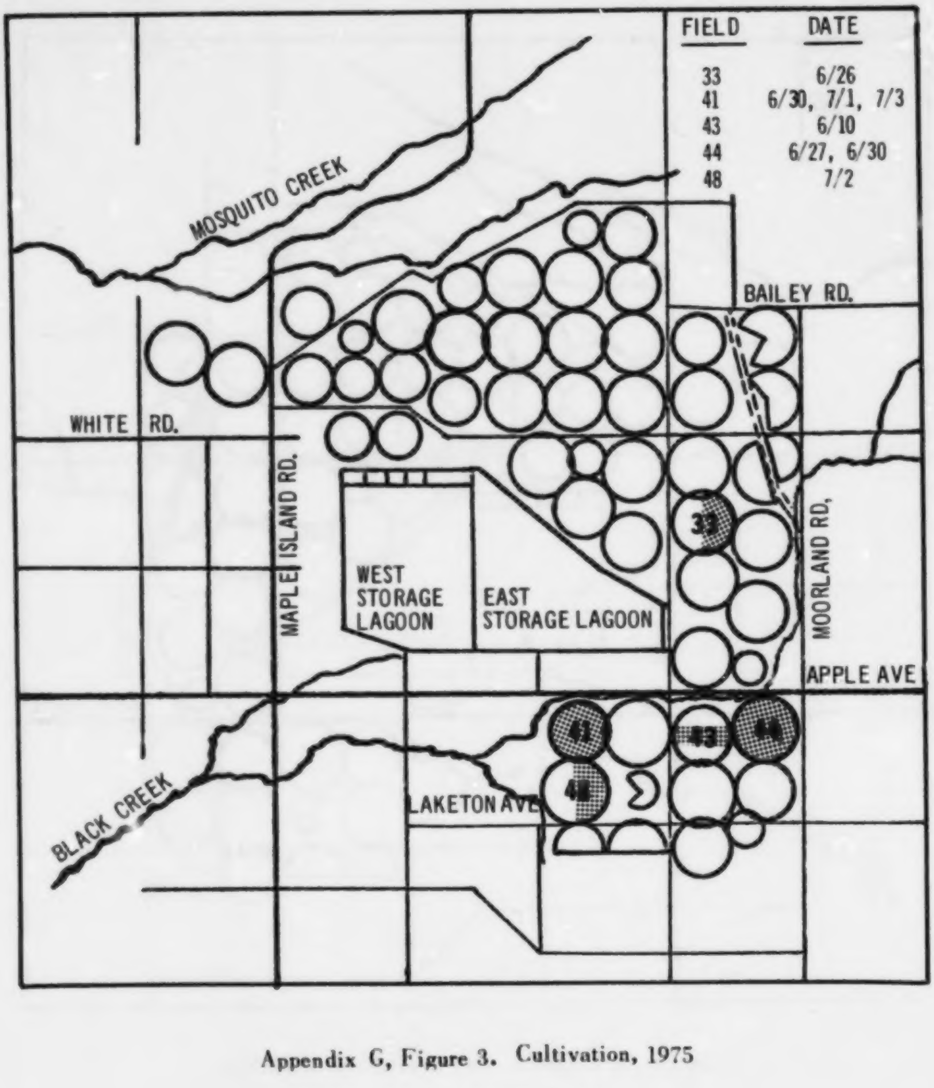
Appendix E Table No.	Column heading	Mean	Standard deviation
15	1974 Crop phosphorus	24.1 kg/ha	14.3 kg/ha
	After crop phosphorus	38.4 kg/ha	21.8 kg/ha
	Total wastewater phosphorus	62.5 kg/ha	32.4 kg/ha
	Fertilizer phosphorus	1.83 kg/ha	6.20 kg/ha
	Available phosphorus	25.9 kg/ha	15.9 kg/ha
	Total phosphorus	64.3 kg/ha	31.9 kg/ha
16	1975 Crop phosphorus	13.9 kg/ha	5.73 kg/ha
	After crop phosphorus	6.51 kg/ha	4.81 kg/ha
	Total phosphorus	21.0 kg/ha	9.76 kg/ha
17	1974 Crop potassium	71.3 kg/ha	45.8 kg/ha
	After crop potassium	78.3 kg/ha	45.5 kg/ha
	Total wastewater potassium	150 kg/ha	84.0 kg/ha
	Fertilizer potassium	25.0 kg/ha	37.0 kg/ha
	Available potassium	96.3 kg/ha	66.9 kg/ha
	Total potassium	175 kg/ha	101 kg/ha
18	1975 Crop potassium	85.4 kg/ha	35.8 kg/ha
	After crop potassium	55.9 kg/ha	41.0 kg/ha
	Total potassium	141 kg/ha	71.1 kg/ha
19	1974 Field days	175 days	12.8 days
	1975 Field days	159 days	8.34 days
21	1974 Rainfall	7.06 cm	4.16 cm
	1974 Critical rain	8.15 cm	4.63 cm
	1974 GDD	1982 GDD	93.8 GDD
	1975 Rainfall	7.16 cm	5.84 cm
	1975 Critical rain	5.92 cm	3.58 cm
	1975 GDD	2320 GDD	67.8 GDD
20	Predicted yield	4.77 Metric tons/ha	1.11 Metric tons/ha
	Percent nozzle plugging	12.0 percent	16.9 percent



Appendix G, Figure 1. Wheat planting, 1974-1975



Appendix G, Figure 2. Wheat planting, 1975-1976



FIELD	DATE
33	6/26
41	6/30, 7/1, 7/3
43	6/10
44	6/27, 6/30
48	7/2

Appendix G, Figure 3. Cultivation, 1975

SECTION 15

GLOSSARY

AAS	atomic absorption spectrophotometry
APHA	American Public Health Association
BOD_5	five-day biological oxygen demand
CMM	cubic meters per minute
COD	chemical oxygen demand
FTU	formazin turbidity units
FWQA	Federal Water Quality Administration
GDD	growing degree days
KWH	kilowatt hour
MCM	million cubic meters
MCMD	million cubic meters per day
MGD	million gallons per day
MPN	most probable number
NPDES	national pollution discharge elimination system
TCMD	thousand cubic meters per day
TDH	total discharge head
TKN	total Kjeldahl nitrogen
TOC	total organic carbon

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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16. ABSTRACT

The Muskegon County Wastewater Management System is a lagoon-impoundment, spray irrigation treatment facility which serves 13 municipalities and five major industries. The system consists of a 4,455 hectare site (11,000 acre) site which contains three aeration ponds, two storage lagoons totaling 688 hectare (1700 acres) and 2,200 hectares (5,500 acres) of land irrigated by center-pivot irrigation rigs. The system is provided with a network of subsurface drains, open interception ditches and shallow wells to make possible the monitoring and control of the quality of water throughout the treatment process. With an average daily flow of 106 thousand cubic meters (28 million gallons) in 1975, the system provided discharge of water of a quality consistently above NPDES specifications. Studies on various aspects of treatment performance, agricultural productivity, and the interrelationships of soil-crop-nutrient chemistry are here reported, including discussions of the socio-economic impact of the project, its early history, a description of its operation and maintenance, and an overview of project economics.

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land use	land pollution abatement	91A
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nutrient removal	municipal wastewater	02D
	rural land use	
	farmland	
	sewage effluents	

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